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WATER FILTRATION WITH COAGULANT INTRODUCED IN THE FILTER

A Thesis Submitted in Partial Fulfilment of the Requirements
of the Degree of

Master of Technology

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TO THE
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
KANPUR

JUNE 1970

CERTIFICATE

This is to certify that the present work has been carried out by Shri Arun Kumar Bhattacharya under my supervision and the work has not been submitted elsewhere for a degree.

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ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to Dr. G.D. Agrawal for his talented and inspiring guidance during the course of present study.

The author also wishes to offer his heart felt thanks to Dr. R.H. Siddiqi and Dr. A.V.S. Prabhakara Rao for their valuable advice from time to time.

The author will fail in his duty if he forgets to thank his friends and colleagues of the Sanitary Engineering Department for their cooperation and help.

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ABSTRACT

A cheap and easy method of water treatment is essential for a developing country like India. The cost of water treatment depends mainly on the cost of chemicals and the cost of back washing of filters. In the present study attempts have been made to use rapid sand filters as a single unit treatment by introducing the coagulant in the filter. It was observed that introduction of coagulant above the filter bed required an alum dose of 10 mg/l to remove 100 mg/l of turbidity. The head loss development was more as compared to one in which coagulant was introduced in the bed. The total depth of bed was not utilised in removing turbidity.

By introducing coagulant in the filter bed at a depth of 3", 100% efficiency of removal of turbidity was obtained with 10 mg/l alum dose. In this case the head loss build up was comparatively low and almost the entire depth of the bed was utilised in removing turbidity. Longer filter runs of 32 hours were obtained by this method and a higher flow rate of 3 gpm/sq.ft was possible with 100% efficiency of removal.

Both the methods of introducing coagulant require less alum dose and solve the question of pretreatment but the latter method in which coagulant was introduced in the filter bed may prove to be more economical in longer runs.

CHAPTER I

INTRODUCTION

1.1 NEED FOR WATER TREATMENT

The object of treating water is to make it potable and safe so as to prevent spread of water born diseases. A supply of water that is fit for human consumption is essential for life. The safe water supply has an actual monetary value. The provision of a water works system furnishing a good quality water will reduce materially the number of deaths and the amount of sickness in a community.

The role of water in the spread of epidemics of enteric diseases has been proved beyond doubt. By the effective utilisation of the modern water treatment procedure enteric bacterial diseases were completely eliminated in some of the advanced countries. This clearly indicates the role of water treatment in checking the spread of enteric diseases.

The incidence of typhoid fever constitutes probably the most significant and accurate measure of the sanitary quality of community water supply, even though the disease may of course, also be caused by the consumption of infectious milk, shell fish and other food. A general picture of reduction in typhoid fever death rate is shown in table no. 1.1, representing data for 78 cities in the United States during the period 1910 to 1946 (1).

TABLE NO. 1.1

TYPHOID DEATH RATE FOR 78 U.S. CITIES 1910-1946

Year	Death Rate Due to Typhoid Fever per 100,000	Year	Death Rate Due to Typhoid Fever per 100,000
1910	20.54	1928	1.89
1911	17.02	1929	1.59
1912	13.14	1930	1.61
1913	13.43	1931	1.63
1914	11.08	1932	1.28
1915	9.47	1932	1.22
1916	8.34	1934	1.19
1917	7.50	1935	0.99
1918	6.73	1936	0.96
1919	4.15	1937	0.82
1920	3.85	1938	0.72
1921	3.95	1939	0.65
1922	3.26	1940	0.48
1923	3.16	1941	0.34
1924	3.07	1942	0.23
1925	3.44	1943	0.22
1926	2.84	1944	0.18
1927	1.99	1945	0.22
		1946	0.15

The creditable reduction in typhoid fever outlined above has resulted in a low epidemic typhoid fever rate in most communities served by Public water supplies.

A more realistic indication of the relationship between improvement in the quality of potable water and reduction of the insidence of typhoid fever is force fully shown by the immediate drop in the typhoid fever rate when water filtration plants are installed. The death toll from typhoid fever in the city of Niagra falls, N.Y. for instance dropped from a rate of 180 per 100,000 to 60 per 100,000 in 1912 when the plant for filtration and chlorination of polluted Niagra river water was placed in service. Subsequently improvements in operation and control reduced the rate to zero by 1926, and only a few deaths from typhoid fever have occured in that city since 1926 (1).

1.2 IMPORTANCE OF FILTRATION IN OVERALL SCHEME OF TREATMENT:

Indicative of the traditional reliance upon filtration to a greater extent than any other type of purification process for the production of water of satisfactory bacteriological quality, is the habit of to-days public in calling most water purification plants as "Filter Plants", although filtration may be only one of the several treatment processes employed. As the efficient mechanical means for floc formation and settling has been made available, reliance on filtration has diminished. Now much greater emphasis has been placed upon the delivery of high quality water to the filter.

Still rapid sand filters have been accepted as one of the satisfactory means of correcting certain defects in available waters which would other wise render them unfit or undesirable for domestic or other uses. Among such defects are turbidity, contamination by bacteria and other micro-organisms and to some extent, taste, color and odor. When bacterial and turbidity loadings are high, rapid sand filtration has an advantage over slow sand filtration; especially in the ease and speed with which a rapid sand filter may be washed and returned to service.

In a country like India where money is the most important criteria in installing a water treatment plant for rural areas or for a big community, design of cheap and simple treatment plants is essential. At present most of the treatment plants in India are being operated at their maximum capacities due to the growth in population and fast urbanisation. It is very difficult to install a new treatment plant. One appreach in this direction may be to use any one of the treatment processes to its full capacity to get suitable water for drinking. Filtration seems to be the best one which can be used as a single unit treatment.

1.3 WATEP TREATMENT IN INDIA

Before the advent of rapid sand filters in India slow sand filters were in use. The slow sand filters are un-suited to treat water containing large amount of organic

matters. When they were first introduced in the country the sources of supply were not polluted with sewage and trade wastes as they are now due to increase in population and fast urbanisation. Their filtration rate is so low that they can not fulfill the demands of growing cities. For these reasons the slow sand filters have been replaced by rapid sand filters for the past 40 years in the country.

The Government of India is trying to improve the water supply system in cities and particularly in rural areas.

In the first 3 five year plans we have not been able to achieve too much in the field of protected water supply. In the fourth plans however a large provision has been made both for the water supply and sewage treatment. The amounts allocated in the first 3 five year plans have been shown in table no. 1.2 (2)

TABLE NO. 1.2

MONEY ALLOCATED FOR HEALTH DEVELOPEMTNT SCHEMES

Plan	Total outlay of plan in crore rupees	Health development schemes in crore rupees	Water Supply and sanitation in crore rumpees
1	2356	140	49
2	4500	225	76
3	10400	3411	105.3

The above figures show that the outlay of health development schemes represent 5.9% in the first, 5% in the second and 3.4% in the third plan in relation to the total outlay in successive plans. For a big country like ours having huge area and large population these amounts seem to be inadequate

1.4 OBJECTIVE OF THE PRESENT STUDY

In the water treatment plants the main operating cost is due to the cost of chemicals and the cost of water used for back washing of filters. If the water is flocculated before filtration the filters get chocked quickly because of the surface cake formation. This reduces the length of filter runs and full depth of filter bed is not utilised. It may be possible to utilise the whole depth by introducing the coagulant in the filter as a solution. Because of the larger contact area available it may be possible to get good effluent quality with less coagulant dose. This may also increase the filter runs due to the utilisation of full depth of bed, by the formation of flocs as the alum will proceed through the bed.

The main aim of the present study is to see the effects of the coagulant addition in the filter as a solution. The study is directed to the following aspects of the overall problem.

1. To see the effects of introduction of coagulant dose in the filter under following conditions.

a. When added to influent water

b. When added in the filter bed.

2. To find out the depth at which the introduction of coagulant gives best results.

3. To see the effects on filtration rates with the above method of introduction of alum.

4. Length of filter run.

CHAPTER II

LITERATURE REVIEW

2.1 HISTORY OF FILTER CONSTRUCTION AND OPERATION

The seperation of solids from liquid by filtration is a natural phenomenon in the clarification of water by drainage through granular soil. This method of clarification has been copied by man, since he became aware of the need for purifying water to make it potable.

The crude form of seperation by straining through porous materials are described by earliest Chinese writers, capillary syphoning was depicted in Egyptian tombs (3). Household and industrial filters were used prior to 1804. It is generally considered that filtration for municipal purposes began in 1829 with the construction of slow sand filters by James Simpson for Chelsea water company London (4).

The early filters were employed merely to remove turbidity by simple straining, but it was found that they operated better after having been in service for a time and after organic matter has accumulated on their surface.

The first rapid sand filter was built in Somerville N.J. in 1882 (4). To the raw water was added a coagulant that formed a mat on the filter surface to serve as a substitute for the bacterial layer of slow sand filter. Since the accumulation of coagulant and retained solids rapidly cause head loss, it was necessary to clean the sand at

frequent intervals. This was done by reversing the flow through the bed and disposing of the dirty water.

2.2 HEAD LOSS IN FILTER BED

In the early years of the filter development most of the research work was done to find out the head loss in the filters. J. Kozeny (5) and G.M. Fair (6) working independently derived an equation for the hydraulic gradient through a bed of clean sand starting with Poisellue's Equation for laminar flow through a circular capillary as follows.

$$i = \frac{32\gamma}{g} \frac{1}{Dt^2} V \quad \ldots \quad (1)$$

Where i denotes the hydraulic gradient, γ denotes the kinametic or absolute viscocity of fluid = μ/ρ , g represents gravity constant, Dt stands for tube dia and V is the mean velocity. Kozeny (5) noted that Dt^2 may be replaced by a constant times the square of the hydraulic radius and the average hydraulic radius in a unit volume of filter equals the pore volume divided by the surface of sand grains.

$$\text{Pore volume} = (P/1-P)\,\text{volume of grains} \quad \ldots \quad (2)$$

$$\text{Volume/grain} = \beta d^3 \quad \ldots \quad (3)$$

$$\text{area/grain} = \alpha d^2 \quad \ldots \quad (4)$$

Where P = porosity ratio, d = grain dia and α and β indicate shape factors, S, (6 for spheres to 9 or more for angular grains).

Hydraulic radius $= P/1-P \cdot d/s$ ... (5)

Because the velocity through the pores V, is v/P in which v represents approach velocity or the rate of filtration, the hydraulic gradient can be written as follows.

$$i = \frac{J\, S^2 \nu}{g} \cdot \frac{(1-P)^2}{P^3} \cdot \frac{v}{d^2} \quad \ldots (6)$$

The value of dimensionless constant J in equation (6) is approximately 6 for filtration and $S^2 = 36$. The equation 6 is applicable only for uniform grain size. It may be used for any thin layer in a rapid sand filter in which the sand has been stratified according to grain size by back washing.

Rose (7) has developed the following equation, to find out the resistance offered to the flow by beds of granular material, by dimensional analysis.

$$h/l = 1.067 \; \frac{C_D}{g} \cdot \frac{1}{P^4} \cdot \frac{v^2}{d} \quad \ldots (7)$$

$$= 0.178 \; \frac{C_D\, v^2\, A}{g\, P^4\, V} \quad \ldots (8)$$

Where d is the diameter of sand grain defined as 6V/A. V and A are respectively the volume and surface area of sand particle.

h = Head loss in depth l.

v = velocity of water moving down upon the sand bed.

P = Porosity ratio of filter bed.

$$C_D = \frac{24}{R} + \frac{3}{\sqrt{R}} + 0.34 \quad \ldots \quad (9)$$

R = Reynolds number

When the flow is laminar C_D approaches a value of 24/R and the equation becomes;

$$h/l = 25.6 \ \frac{\gamma}{g} \cdot \frac{1}{p^4} \cdot \frac{v}{d^2} \quad \ldots \quad (10)$$

Where γ is the kinametic viscosity of water.

John L. Cleasby et at (8) have shown that the total head loss in the filter bed is the sum of the surface cake head loss development and the head loss development in the sand bed. The head loss in the sand bed developes in a linear manner because rigid matrix of sand grains prevent compression of the deposited materials. Head loss in the compressible surface increases exponentially as the filter run progresses. The exponent depends upon cake compressibility.

For clean filter bed head loss per unit depth is constant throughout the bed. As the run proceeds the slope of head loss curve will increase which is due to the change of characteristics of deposition of suspended matter in the pores of the bed. If there was no suspended matter in the influent water there would have been no change of initial head loss per unit depth during the length of the filter run.

2.3 FILTRATION EQUATION

In 1937 T. Iwasaki (9) first suggested that the change of concentration of particles per unit depth, filtering through a column of granular media is proportional to the instantaneous concentration as;

$$-\frac{\delta c}{\delta l} = \lambda c \qquad \ldots \qquad (11)$$

on integrating

$$C = Co \quad e^{-\lambda L} \qquad \ldots \qquad (12)$$

Where Co = concentration of suspension in influent water in volume/volume ratio.

C = concentration of suspension at any depth of filter in volume/volume ratio.

L = depth below filter surface

λ = filter coefficient.

Filter coefficient λ represents the rate of removal of suspended matter along the depth and is thus a measure of the efficiency of the filter. The value of λ depends upon the following parameters.

1. Characteristics of suspension.(eg Size, density).
2. Rate of filtration
3. Water viscosity
4. Internal geometry of the pores.
5. Probably, characteristics of the filter media.

During filter run suspended matter is removed and is deposited in the bed, thus the pore shape and size varies

with depth of filter and time of filter run. At the surface the concentration of suspension in flow is Co and at the begining of the filter run filter media is clean. Therefore $\lambda = \lambda_o$.

Where λ_o = initial filter coefficient.

At zero time the equation (12) becomes;

$$C = Co\ e^{-\lambda_o L} \quad \dots (13)$$

It was observed by Iwaski (9) and others that the efficiency of a filter initially increases from the start of run as the floc is deposited. Iwasaki and later Ives (10) used a linear equation to relate the filter coefficient with initial filter coefficient and the specific deposit of floc as follows;

$$\lambda = \lambda_o + C\sigma \quad \dots (14)$$

Where σ is the specific deposit of floc or volume of floc deposited/unit bed volume and C is a constant.

As the deposition increases pores become constricted tending to increase interstitial velocity and reduce the interstitial surface area for deposition. Thus the value of λ reduces. The above equation No.- 14 has been modified by Ives (10) as follows;

$$\lambda = \lambda_o + C\sigma - \frac{\phi\sigma^2}{f_o - \sigma} \quad \dots (15)$$

Where f_o is the initial porosity of the bed and ϕ is the rate factor parameter.

Recent researches by Ives (11) and his co-workers have corelated the constants λ_o, C, and ϕ to 3 fundamental parameters of a filter.

$$\lambda_o = \frac{K_1}{d_m V_o \mu^2} \quad \ldots \quad (16)$$

$$C = \frac{K_2}{d_m V_o \mu^{1.2}} \quad \ldots \quad (17)$$

$$\phi = \frac{K_3}{d_m V_o \mu^2} \quad \ldots \quad (18)$$

Where K_1, K_2 and K_3 are constants.

V_o = superficial velocity of filtration

μ = viscosity of water.

d_m = mean diameter of grain.

The above correlations are of limited use; since K_1 K_2 and K_3 will have to be found experimentally for each system.

2.4 NEED FOR COAGULATION AND FLOCCULATION

The objectionable colloid and other finely divided matter may include clay, silt, organic matter and micro-organisms. When concentration of these impurities do not exceed a certain low limiting value, satisfactory removal may be obtained by slow sand filtration without the use of coagulant. But more and more often the necessity of coagulant is being felt in order to get more amount of filtered water in short time or to handle raw waters with poorer initial quality.

The principal function of coagulation is the destabilisation, aggregation and binding together of colloids. In water treatment chemical coagulation involves the formation of chemical flocs that absorb, entrap or otherwise bring together suspended matter, more particularly the suspended matter that is so finely divided as to be colloidal.

The objective of a conventional treatment plant is to produce floc of such size and density that the major portion settls out in the settling tank and the amount of remaining turbidity will be removed by the filter.

Ives (11) and his co-workers did some experiments to find out the different variables affecting filtration. They found that the influent concentration of turbidity entering the filter is one of the most important factor which affects filtration. The results obtained by them are given in table no. 2.1

TABLE NO. 2.1

COMPARISION OF FILTER PERFORMANCE UNDER DIFFERENT OPERATING CONDITIONS

Filter conditions	Inlet conc. in ppm	Depth to give filtrate <10 PPM in inches	Run to keep filtrate <10 PPM in hour	Run for 5 ft head loss in hours
1. Normal	200	24	40	34
2. Double rate	200	48	50	6
3. Larger grain	200	39	80	37
4. Normal	20	24	>50	>48*
5. Increased temp.	200	24	50	36

*only 17" head loss after 48 hrs. Filtrate below 5 PPM

The typical filter conditions during the experiment were as follows;

Rate of filtration 2 gpm/sq.ft.

Grain dia = 22 - 25 sieve size, d = .065 cms,

Water temp. 10°C

From the above table it can seen that, if the water flowing to the filter were pretreated to reduce its turbidity from 200 ppm to 20 ppm, the filter produced a filtrate consistantly below 5 ppm with only 17" of head loss after 48 hours of operation. This increased the length of the filter run to a reasonable extent.

2.5 FLOC STRENGTH OR TOUGHNESS

S.A. Hannel (12) and Coworkers have shown that the floc strength is one of the factors that affects the success with which suspended solids are removed from the water during sedimentation and filtration. They have defined the floc strength as the resistance to fragmentation by shear induced by hydraulic velocity gradient. A strong floc is formed rapidly under a high velocity gradient, while a weaker floc will not grow in size or will disintegrate under some conditions.

During filtration excessive floc strength will cause bulk of the floc to remain within the upper layers of the filter and the tendency for break through will be smaller. This advantage is more than offset by a rapid increase in head

loss in the upper layers. Some intermediate strength is desired, where the floc gradually penetrates in to the bed for the removal of solids without premature break through.

2.6 MECHANISMS OF REMOVAL OF PARTICLES

To explain various observed phenomenon in filtration practice, several different mechanisms of removal of suspended matter have been proposed. They may be divided in to two groups.

1. Purely physical mechanisms
2. Chemical mechanisms.

The physical mechanisms of removal are;

1. Direct sieving or straining.
2. Sedimentation.
3. Inertial impingement.
4. Brownion movement.
5. Chance contact caused by convergence of fluid stream lines.
6. Diffusion caused by a suspended particle concentration gradient.

The chemical removal mechanisms are;

1. Van der Wall's effect.
2. Electrokinetic phenomenon.
3. Coagulation within the filter bed.

2.6.1 Physical Removal Mechanisms: The physical removal mechanisms depend primarily on physical and operational variables including;

1. Sand size. 2. Suspended particle size 3. Suspended particle density 4. Filtration velocity 5. Fluid viscosity and 6. Temperature.

a. Mechanical Straining: This is one of the simplest mechanisms proposed for filtration. Fair and Gayer (13), Camp (14) and Hall (15) all assigned most of the removal to this mechanisms along with settling and inertial impaction.

It takes place almost entirely at the surface of the filter where the water enters the pores of the filter bed. Initially straining removes only those substances that are larger than the pore size. As the filtration is continued, the substances strained out accumulate on the surface of the filter as a mat through which the water must pass before it can reach the filter medium itself. Removal of impurities is thereby further restricted to the surface of the filter.

Several authors have advanced the view that a portion of the finer particles would be removed at the narrow corners of the interstices. The quantity so removed in case of interstices between spherical grains of diameter d_m has been evaluated by Hall (15). According to him the fraction of particles of size d_p removed is,

$$r' = 35\ C\ \left(\frac{d_p}{d_m}\right)^{1.5} \qquad \ldots \quad (19)$$

Where r' is the fraction of particles removed. C is a constant. The value of 'C' given by Hall (15) is equal to 0.1.

Later on Agrawal (16) has shown that the area of interstices is 0.4 dm^2 in place of 0.303 dm^2 as obtained by Hall (15). Thus the fraction of particles of size d_p removed becomes;

$$r' = 26.5\ C\ \left(\frac{d_p}{d_m}\right)^{1.5} \qquad \ldots (20)$$

Since this is a fraction removed per layer of media, this could be converted easily to λ_o for straining.

$$(\lambda_o)_{st} = \frac{1}{d_m}\ 3.5\ \left(\frac{d_p}{d_m}\right)^{3/2} \qquad \ldots (21)$$

$$= 3.5\ d_p^{3/2} \cdot d_m^{-5/2} \qquad \ldots (22)$$

b. Gravitational Sedimentation Theory. This has often been considered the most significant mechanisms for removal in filters. Each pore can be considered as samll sedimentation basin in which the flow slows down enough in the wide part of the pore to allow the particle sufficient time to settle on the surface of sand grain.

Hall (15) has developed the following theory considering the flow of a suspension of uniform size particles through a sand bed. The direction of flow is parallel to the acceleration due to gravity. If the density of the particles and the water is same, the velocity and path of the particle would be identical to the velocity and streamline of the fluid. Since the density of particle is more than water, an unbalanced force will exist initially and the particle will accelerate relative to the fluid until a particle velocity relative to the fluid is

reached. In this case viscous drag is equal to the unbalanced gravitational force. A second force exists due to the curvature in stream lines in passing around a sand grain. In filtration acceleration due to gravity is much greater than the acceleration due to curvatures. The suspended matter may thus be considered to be moving down wards every where in the filter with a velocity relative to fluid. Hall (15) has shown that the rate factor for gravitional theory is;

$$r' = C' \; m \; d_p^{\,2}/v \qquad \ldots \quad (23)$$

Where $$m = 2/9 \left(\frac{\gamma - \gamma_0}{\mu}\right) \qquad \ldots \quad (24)$$

d_p = diameter of particles

v = mean velocity of flow

γ = specific weight of particles

γ_o = specific weight of water

μ = viscocity of fluid

From experimental data Hall (15) has found the value of the constant C' to be equal to 0.1.

c. <u>Inertial Impingment</u>: As a suspension flows through a filter media it must continually change direction to permit flow around the randomly oriented sand grains. Inertial effects can cause particles with sufficientmomentum to continue in their original paths and impinge on the sand grains. Chen (17) has presented the following relationship describing this phenomenon;

$$p_i \propto \frac{\rho_p \; D^2 \; v}{fd} \qquad \ldots \quad (25)$$

in which p_i is the probability of impingement of particles of diameter D on a cylindrical collector of diameter d, v is the particle velocity, ρ_p is the particle density and f the fluid viscosity. Inertial impingement is the predominant removal mechanisms in fibrous filters used to clean air. It is not of great significance in rapid sand filters owing to high viscosity of water.

d. Brownion Movement: Several investigators, Stanley (18), Chen (17), have discussed Brownion movement as a mechanism for bringing suspended particles in to contact with the surface of the filter mediaum. All have agreed that it is insignificant in rapid sand filtration. Einstein's equation for the translation of a spherical particle due to Brownion motion may be stated as follows;

$$\bar{x} = \left(\frac{2\ k\ T\ t}{3\ \pi\ f\ D}\right)^{\frac{1}{2}} \quad \ldots. \quad (26)$$

Where $\bar{x}$ is the mean translation of a particle of diameter D in time t, k is the Boltzmann's constant ($k=1.38 \times 10^{-16}$), T is the absolute temperature and f is the fluid viscosity. The equation shows that the mean translation decreases inversly with the square root of the particle size. Calculations show that this removal mechanisms has little effect for particles larger than 2 μ size (19).

e. Change Contact: Stein (20) has investigated that the removal of suspended particles produced at constrictions in a tube, with a sand bed considered as a vast newwork of

constricted tubes. In flowing through a constriction, suspended particles can be brought in to contact with the sand surface by the converging fluid stream lines. Stein proposed the following relationship.

$$p_c \propto \frac{d_p^2}{d_m^3} \qquad \ldots \quad (27)$$

In which p_c is the probability of removal of suspended particles of diameter d_p in the process of flowing through a unit length of bed comprised of grains with diameter d_m. The mechanism has also been proposed by Grace (21) for the removal of small spherical iron particles from a Glycerol water solution by fibrous media.

f. Diffusion: Diffusion of suspended particles in the porous medium has been proposed as a removal mechanism by Hunter and Alexander (22). This proposal was based on their studies of the flow of kaolinite suspension through silica sand beds. Both the sand particles and the sand surface exhibited - ve Zeta potentials of similar magnitude. These authors considered the filter bed to consist of regions where the liquid flow approximates that in a capillary and regions where the liquid flow is essentially zero. When a a clay suspension is passed through such a porous medium clay particles diffuse across fluid stream lines to these dead spaces because of particle concentration gradient initially present. It has also been proposed that the clay concentration in the dead spaces can become considerably higher

than in the bulk fluid because of tendency for colloidal particles to migrate to regions of low shear even against concentration gradient (19).

2.6.2 Inadequacy of Physical Means: In recent years investigations of the filtering properties of suspensions containing non flocculant materials have indicated that these physical removal mechanisms cannot adequately explain observed filter performance, either in the field or in the laboratory Ghosh (23) investigated the filtering properties of uncoagulated diatomaceous earth suspension and found considerable turbidity penetrating the entire bed depth under almost all conditions of flow. Borchardt and O'Melia (24) investigated the filtering properties of uncoagulated algal suspension by using filter sand ranging in size from 0.316 to 0.524 mm and flow rate ranging from 0.15 to 2.16 gpm/sq.ft. Significant number of algae were found in every effluent sample collected and removal efficiency of less than 10% were not uncommon.

Numerous investigations on the filtering properties of coagulated water has been made. Eliassen (25) conducted research on rapid sand filtration of ferric floc suspension. Microscopic measurements of the influent floc particles indicated an average size of 11 μ. It was found that most of the applied suspensions were removed in the upper layers of the bed and the burden of removal was transffered gradually to the lower portions of the filter as the run progressed.

Small concentrations of iron were found in the filter effluent as the run progressed.

It is apparent that considerable differences exist in the degree of particle removal produced by a rapid sand filter. These depend on the type of turbidity in the filter influent. Physical removal theories that attempt to explain these differences in terms of sand size, suspended particle size and flow rate are unsuccessful.

2.63 Chemical Removal Mechanisms: All solid particles have a charge on their surface when placed in contact with water for one or more of the following reasons (19).

1. Ionisation of molecules at the particle surface.
2. Unsatisfied charges because of imperfection in crystal lattice.
3. Direct chemical reaction with specific ions in solution, which result in the formation of a chemical bond.
4. Weaker physical adsorption of ions from solution as produced by hydrogen bonding or Van der Wall forces.

At the solid liquid interface a tightly held layer of ions of opposite charges termed as the stationary layer and a second more loosely bound layer of ions (also of opposite charges) termed as the "diffuse layer" are produced. This electro-chemical double layer always exerts a repulsive potential between similar particles in an aquaous suspension. The magnitude of this potential and the distance over which it acts are significantly affected by the chemical composition of the aquaous phase.

a. <u>Electro Kinetic Effects</u>: Stanley's (18) research has indicated that the iron floc particles filter best (that is produce least bed penetration) in the pH region encomprising their isoelectric point, and that their filtrability is also affected by the type of ions in water. The presence of 500 ppm of Na Cl, Na_2 SO_4 and $MgSO_4$ increased the rate of bed penetration significantly. Stanley (18) proposed that the suspended particles are most easily removed when their electrokinetic repelling forces are at a minimum.

Cleasby and Baumann (8) observed that feric floc particle size has little effect on the removal efficiency of a filter. Infact suspension of large particles (20 - 100 µ) were found to be less filtrable than those containing smaller particles (1 - 20 µ). The investigators concluded that electrokinetic forces were primarily resposible for the removal of hydrous ferric oxide particles.

Oulmann and Baumann (25) have investigated streaming potential in the passage of water through diatomaceous filters. They demonstrated that diatomaceous earth normally exhibits a negative surface charge in contact with water, and that this charge can be reversed to positive values by treating the diatomite with iron or aluminium salts and with cationic poly-electrolyte. It was concluded that -vely charged colloidal particles too small to be removed by physical processes could be retained by mutual coagulation when the diatomite filter exhibits + ve surface charge

b. Van Der Wall Forces In addition to the interaction between electro-chemical double layers, particles are also affected by Van der Wall forces. These are molecular cohesive forces between particles which increase in intensity as the particles approach each other. Between these atoms these forces are proportional to r^{-7} where r is the distance separating the atoms (19). These forces are additive so that in a collection of atoms each atom attracts other atoms. For large particles composed of many atoms these forces are proportional to r^{-3} and the attractive potential is proportional to r^{-2}.

Mackrle and Mackrle (28) have developed a model for sand filtration process based on considerations of Van der Wall's attractive forces. These authors contented that adhesion between suspended particles and the filter media is controlled by Van der Wall's forces and assumed that electro-kinetic effects are insignificant.

Adsorption of suspended particles to the surface of the filter medium has been proposed by Ives (28), Stein (20) Camp (29) and many other investigators as an important factor in rapid sand filtration. Adsorption is not solely dependent upon the physical characteristics of the suspension and the filter. It is dependent upon both electro-chemical and Van der Wall's forces and consequently it can be affected by the chemical characteristics of the suspended particles.

c. Coagulation in Filters: Some investigators have proposed that straining and sedimentation of floc particles in a sand bed are increased by suspended particle growth produced by flocculation within the pores of the filter. Particle growth could therefore explain the higher removal efficiency observed for flocculant particles. A consideration of the flocculation process however leads to the conclusion that this mechanism is insignificant in rapid sand filters. Camp (14) and Stein (20) have shown that the rate at which particles are colliding (and consequently the rate at which flocculation is proceeding) is proportional to the mean velocity gradient in a fluid. Calculations presented by Stanley (18) show that mean velocity gradient optimum for flocculation can occure within a filter under certain conditions. The total number of collisions (and consequently the total amount of flocculation produced) is proportional to the mean velocity gradient multiplied by the detention time. For a rapid sand filter this product is considerably low than the required for appreciable flocculation. Thus this mechanism is not of great importance in filtration.

2.7 SIGNIFICANCE OF VARIOUS FILTRATION MECHANISMS ON HEAD LOSS DEVELOPMENT

Theoritical analysis have been made to predict the removal of suspended particles in a given filtration system by the particular mechanisms operative. In real filtration system one or more of the mechanisms may be significant.

As mentioned earlier the head loss in a filter bed is the sum of the surface cake head loss and the head loss developement in the bed. The formation of surface cake is due to the predominance of straining mechanism in the filter bed. This predominance may be due to the finer filter media or bigger suspended particles. Most of the head loss developement in the top layer indicates the predominance of straining mechanism.

When the particles are removed throughout the filter bed the head loss development curve becomes almost linear. The removal through out the depth may be due to interception, diffusion, gravity setteling, electrokinetic phenomenon and coagulation. But as mentioned earlier interception, gravity setteling and coagulation are not important in filtration. If coagulation in the bed is predominant then most of the removal should occure at the lower depths of the bed and the head loss should also be maximum at the lower depths. This shows that when the head loss is uniformly distributed throughout the bed the electrokinetic phenomenon and diffusion are most effective.

2.8 PREVIOUS WORK ON COAGULANT INTRODUCTION IN THE FILTER

Not much literature is available on the introduction of coagulant dose in the filter. Eric Davis and J.A. Borchardt (30) in their studies with algal cells and activated carbon suspension tried different methods of

adding coagulant to accomplish optimum removal. They found that better removal was obtained when coagulant was fed contineously as a solution to the filter influent.

Later on Agrawal (16) in his studies with Bentonite clay and Algal filtration added flocculating agent like Alum or Poly electrolyte just ahead of filter with no flocculation in the conventional sense. This increased greatly the efficiency of filters at the start of the run. The filter performance improved with time as is the general experience in filtration practice. A rapid head loss occured in the top layers and the filter run had to be terminated 2½ hours after start of run for clay filtration and 1½ hours after start of run for algae filtration due to excessive head loss build up.

2.9 SUMMARY

Thus it can be seen that in the early years of filter development most of the work was oriented towards finding out the head loss in the filter bed. After the development of Iwasaki's equation for filtration, attempts were made to increase the efficiency of rapid sand filters. During the past 100 years of water filtration a large number of observations, most often rather qualitative in character, have been made about the variation in filtration efficiency with various parameters of the system and operation conditions. In the recent years greater emphasis is being given to the different removal mechanisms in predicting the filter performance.

In filtration system one, or more likely several, of the mechanisms may be significant. Such uncertainty about the dominant removal mechanisms is a great disadvantage in design and operation of filter systems since it is impossible to determine which parameter can be most easily altered to obtain desired results.

CHAPTER III

EXPERIMENTAL METHODS

3.1 APPARATUS AND EQUIPMENTS:

a. Filter Column: Three inches diameter G.I. pipe was taken to make filter columns. Rose (7) has stated that the diameter of filter column should be atleast 50 times the diameter of sand to avoid wall-effect. In the present study the mean size of sand was 0.3 mm. By taking 3" diameter of column the wall effect was eliminated. The filter column was 5 ft. long 1/32" diameter holes were drilled on both sides of the filter column at 3" above and 3", 6", 9", 18", 33" and 36" below the surface of the filter bed. ½" diameter nuts were welded on the filter column keeping the 1/32" diameter holes at the centre of the nut hole. The details of the filter column has been shown in figure no. 3.1.

Brass tappings as shown in figure no. 3.1 were used to fix in the nuts welded on the filter columns. The brass tappings were of ½" diameter for ½" length and threaded. The other ½" length was of ¼" diameter. The tappings had a 1/16" diameter holes at the centre.

b. Over Head Tank: All the filter columns and the overhead tank were arranged as shown in figure no. 3.2. The overhead tank was made of a circular drum. It was 22" in diameter and 28" long. The tank had an overflow pipe connected at 6' from top to maintain constant head in the

tank. The capacity of the tank was 131 litres. Water was fed in to the tank from a tap.

c. Manometers: ¼" diameter glass tubes were used as manometers. The tubes were fixed on a board 8 ft. long. The length of the manometers was 8 ft. They were connected to the brass tappings of the filter column with the help of polythene tubes. The tappings on the otherside of the filter column were used for taking out sample from the filter.

d. Filter Media: Sand was used as filter media. Gravel was used as the supporting media for sand. The total depth of media was 3 ft. The bottom 6" layer was of gravel of ½" to 1" size. Above it a 6" layer of gravel of ¼" to ½" size was placed. Above it 2 ft. bed of sand was placed. The sand used was one which passed through No. 25 B.S. Sieve and retained on 36 B.S. Sieve. The sand and the gravel were washed with water and dried before use. The arrangement of the filter media has been shown in figure no. 3.1.

e. Feed Suspension: Kaolinite ($Al_2\ Si_2O_5(OH)_4$ was used to prepare feed suspension. The kaolinite used had 37% clay and 63% silt ( ). The kaolinite was dried before use. A suspension of known concentration (10000 mg/l) was prepared and was fed to the overhead tank from a bottle to keep the concentration in the overhead tank constant at 100 mg/l.

f. Coagulant: Analytical reagent grade potash alum, $Al_2(SO_4)_3 \cdot K_2SO_4$, 24 H_2O was used as a coagulant. The coagulant was fed as a solution from a bottle kept above the

overhead tank. Distilled water was used to prepare the solution. The flow rate of the coagulant was adjusted with the help of a screw cock.

g. Water: Institute tap water was used in all the experiments.

h. Spectro Photometer: Bauch and Lomb spectronic 20 was used to measure the turbidity of the samples. The wave-length used for determination was 390 mu.

3.2 EXPERIMENTAL PROCEDURE:

3.2.1 Tap Water Analysis: The tap water used in the experiments was analysed for alkalinity, hardness, total solids, bicarbonates and sulphates. The analysis was done as given in Standard methods (31).

3.2.2 Determination of Turbidity: Determination of turbidity was made by measuring the optical density or absorbance of light by B and L spectronic 20. The optimum wavelength giving the maximum absorbance was found to be 390 mu. At this wave length the absorbance of the various concentrations ofsuspension were found and a curve was plotted. This curve was used to find out the turbidity of the samples.

3.2.3 Effective Size of Sand: The effective size of sand and the uniformity coefficient were found by sieve analysis. 500 grams of sand passing through 25 B.S. Sieve and retained on 36 B.S. Sieve was taken. This was kept in a shaker containing a set of B.S Sieves. The sieves used were B.S.S. No. 7, 25, 36, 52 and 100. After 10 minutes of shaking the amount of

sand retained on each sieve was weighed. By plotting these values on a Semi log paper the uniformity coefficient and the effective size of sand were calculated.

3.2.4 Optimum Alum Dose: Jar test was done to find out the optimum alum dose required for 100 mg/l of turbidity. 500 ml portions of sample having 100 mg/l turbidity were taken in jars. Alum was added in different doses to different jars. It was flocculated in laboratory flocculator at the rate of 60 RPM for 15 minutes. Then the samples were allowed to settle for 30 minutes. After 30 minutes the turbidity of the supernatant were observed with the help of spectro photometer. A plot betweed alum dose and the turbidity of the supernatant was made and the optimum alum dose was found. The different doses of alum used were 0, 5, 10, 15, 20, 30, 35 and 40 miligrams.

3.2.5 Preparation of Turbid Feed Water: Initially 13.1 grams of kaolin was added in the drum since the capacity of the drum was 131 litres. This gave 100 mg/l turbidity in the drum. Adjusted amount of turbidity was added contineously in the tank from a bottle. The addition of the amount of turbidity depended on the quantity of water inflow to the tank. The turbidity of the water in the tank was checked at a regular interval of 1 hour.

3.2.6 Feeding Alum Solution in the Filter: The alum solution was fed to the filters through the brass tappings. All the three filters were run simultaneously. The first

filter was run without any alum dose. In the second filter alum was fed to the influent water 3" above the filter bed. In the third one alum was fed into the filter bed 3" from top of the bed.

3.2.7 Rate of Flow Control. At the start of the experiments the flow through the filters were adjusted to 2 gpm/sq.ft of the filter bed. It was adjusted with the help of a valve fitted at the bottom of the filter columns. The flow was maintained constant throughout the experiment.

3.2.8 Filter Runs: Filter runs under following conditions were taken to see the performance of the filters.

1. Filter runs without any alum dose.

2. By feeding the alum dose to the influent water 3" from the top of the bed. 60, 40, 20, 10 and 5 mg/l doses of alum were tried.

3. Feeding the alum dose in the sand bed 3" below the top of the bed. 60, 40, 20, and 5 mg/l doses of alum were tried.

4. Feeding the alum dose at different depths of the filter bed. In this case an alum dose of 10 mg/l was used and was fed at 6" and 9" from top of the bed.

5. Filter runs at increased flow rates. Flow rate of 3 and 4 gpm/sq.ft were used.

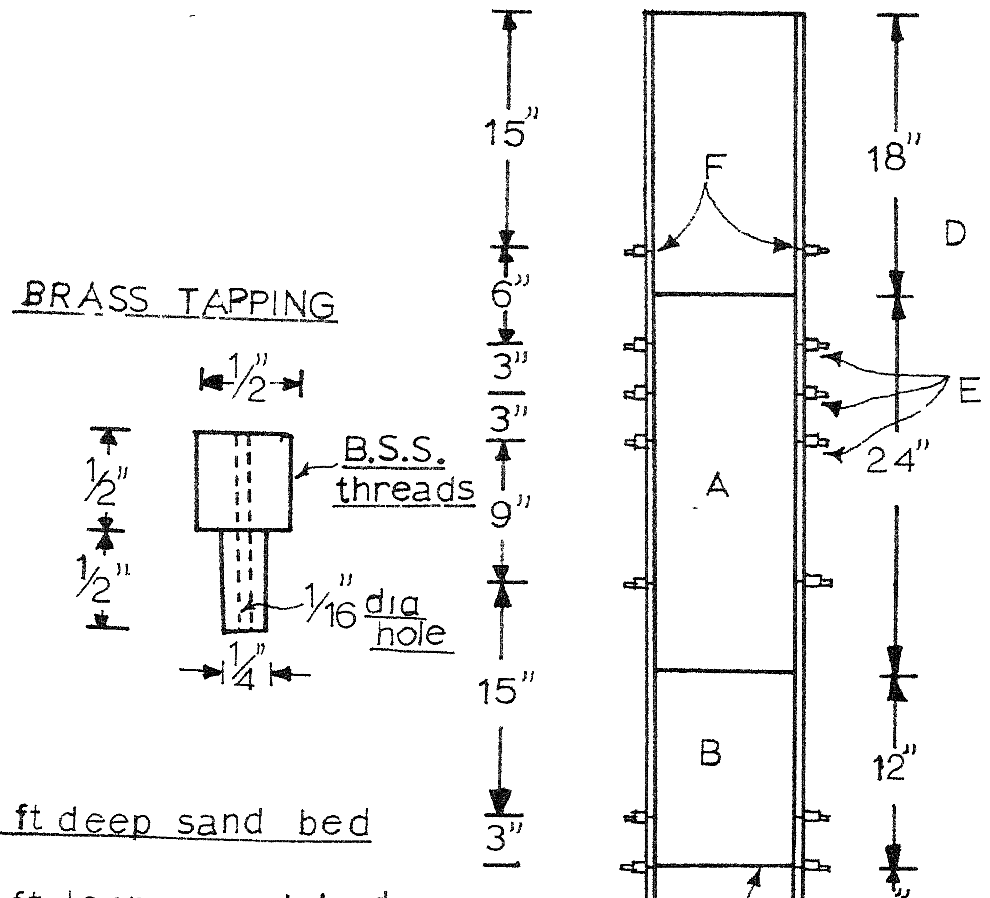
6. Filter runs to find out the total time for which the filter can be run without needing a back wash.

In all the above filter runs the head loss and the turbidity at different depths of the filter bed were found every hour. Before taking the observations the flow through the filters were adjusted to the flow rate at which the filter was run.

3.2.9 Filter Back Wash: The filters were back washed after every filter run to remove the deposited materials in the filter bed. This was done with tap water. The lower end of the filter was connected to the tap. Back washing was continued untill clear water started comming out from the filter.

Figure No-3·1

Details Of Filter Column



A 2 ft deep sand bed

B 1 ft deep gravel bed

C wire mesh

D brass tappings

E 1/2" dia. nuts

F 1/32" dia holes

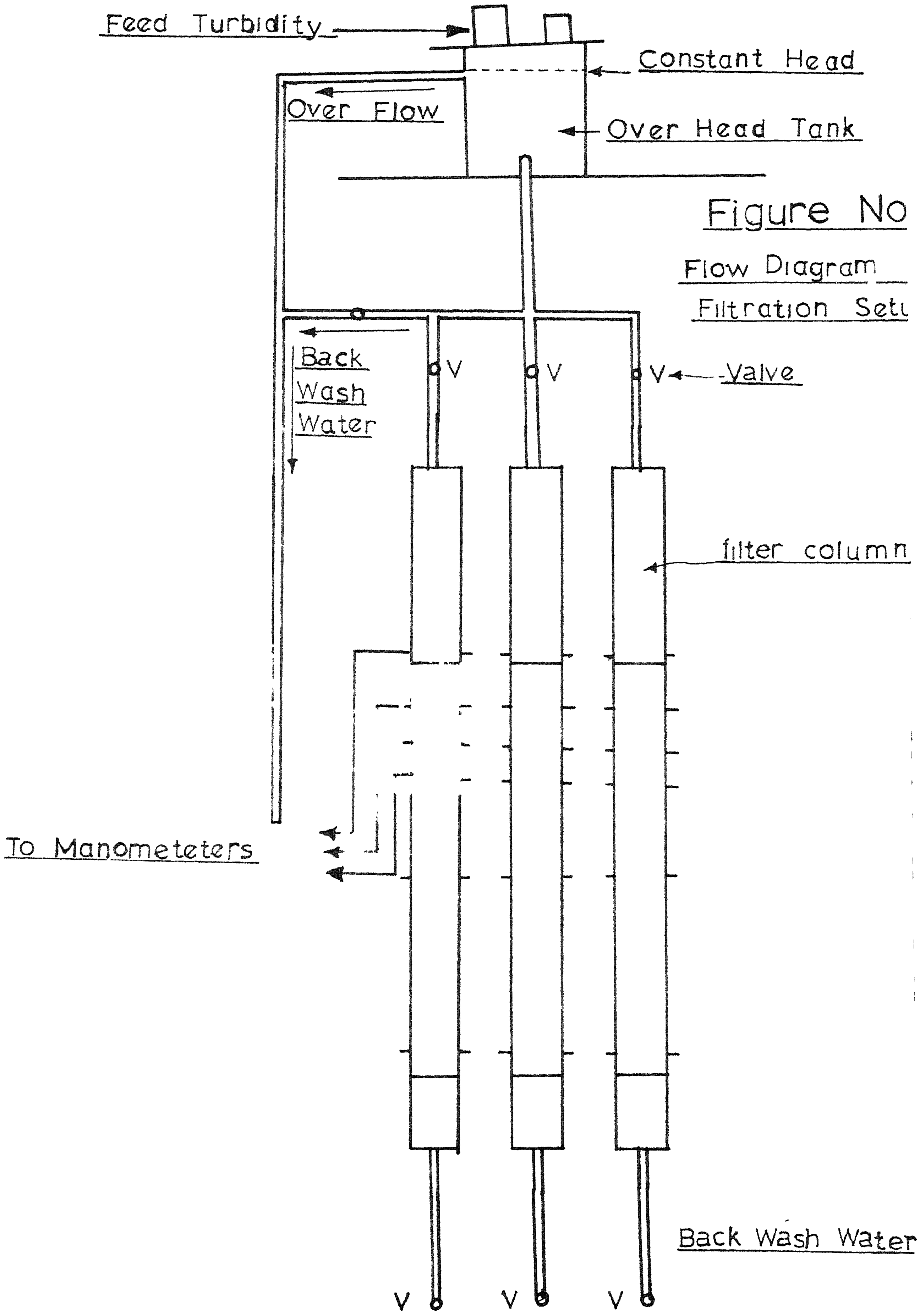


Figure No

Flow Diagram

Filtration Setu

CHAPTER IV

EXPERIMENTAL RESULTS

4.1 GENERAL:

a. Tap Water Analysis : Analysis of the tap water used in the experiments aregiven below.

TAP WATER ANALYSIS

1.	pH	8.3
2.	Alkalinity	540 mg/l as $CaCO_3$
3.	HCO_3^-	540 mg/l as $CaCO_3$
4.	Hardness (Total)	200 - 220 mg/l as $CaCO_3$
5.	Ca^{++} Hardness	180 - 190 mg/l as $caCO_3$
6.	$SO_4^=$	40 mg/l
7.	Total Solids	680 mg/l

b. Determination of Turbidity: The absorbance for various turbidities have been plotted in figure No. 4.1, 4.2. The optimum wave length was obtained as 390 mu. The values obtained are given in Appendix table No. 1.

c. Effective Size of Sand: The results obtained by sieve analysis of sand has been shown in figure No. 4.3. The values obtained are given in table No. 2.

$$\text{Uniformity coefficient of sand} = \frac{D60}{D10} = 1.42$$

Where D60 = Diameter of 60 percentile.

D10 = Diameter of 10 percentile.

Mean size of sand = D10 = 0.3 mm.

d. Optimum Alum Dose: The optimum dose of alum required for 100 mg/l of turbidity was found to be 60 mg/ (figure No. 4.4). The values are given in table No. 3.

4.2 FILTER RUNS:

a Without Alum Dose: (Figure No. 4.5 Table No. 4)

Maximum removal obtained = 55%

Head loss in 8 hours = 1.30 ft.

b. Alum Dose Introduced 3" Above Filter Bed: (Flov rate 2 gpm/sq.ft.)

1. Dose 60 mg/l (Fig. No.4.6 Table No. 5)

   Maximum removal obtained = 100%

   Head loss in 8 hours = 7.8 ft.

2. Dose 40 mg/l (Fig. No. 4.7 Table No. 6)

   Maximum removal obtained = 100%

   Head loss in 8 hours = 7.8 ft.

3. Dose 20 mg/l (Fig. No. 4.8 Table No.7)

   Maximum removal obtained = 100%

   Head loss in 8 hrs. = 6.94 ft.

4. Dose 10 mg/l (Figure No. 4.9 Table No. 8)

   Maximum removal obtained = 100%

   Head loss in 8 hours = 3.52 ft.

5. Dose 5 mg/l (Figure No. 4.10 Table No. 9)

   Maximum removal obtained = 92%

   Head loss in 8 hours = 2.11 ft.

c. Alum Dose In The Filter Bed 3" from Top:

1. Dose 60 mg/l (Figure No. 4.6 Table No. 10)

   Maximum removal obtained = 100%

   Head loss in 8 hours = 2.67 ft.

2. Dose 40 mg/l (Figure No. 4.7 Table No. 11)

   Maximum removal obtained = 100%

   Head loss in 8 hrs = 2.2 ft.

3. Dose 20 mg/l (Figure No. 4.8 Table No. 12)

   Maximum removal obtained = 100 %

   Head loss in 8 hours = 1.94 ft.

4. Dose 10 mg/l (Figure No. 4.9 Table No. 13)

   Maximum removal obtained = 100%

   Head Loss in 8 hours = 1.79 ft.

5. Dose 5 mg/l (Figure No. 4.10 Table No. 14)

   Maximum removal obtained = 92%

   Head loss in 8 hrs. = 1.55 ft.

d. Alum Dose Introduced at Different Depths: Flow rate 2 gpm/sq.ft. Alum dose 10 mg/l.

1. At a depth of 6" from top of bed (Figure No.4.11 Table No. 15)

   Maximum removal obtained = 100%

   Head loss in 8 hours = 1.82 ft.

2. At a depth of 9" from top of bed (Figure No.4.11 Table No. 16).

   Maximum removal obtained = 100%

   Head loss in 8 hrs = 1.72 ft.

e. Increased Flow Rates: Alum dose 10 mg/l. Dose added in the bed 3" from top.

1. Flow rate 3 gpm/sq.ft.(Figure No. 4.12 Table No.17)

   Maximum removal obtained = 100%

   Head loss in 8 hours = 2.42 ft.

2. Flow rate 4 gpm/sq.ft.(Figure No.4.12 Table No. 18)

   Maximum removal obtained = 82%

   Head loss in 6 hours = 3.38 ft.

f. Long Filter Runs: Dose of Alum 10 mg/l, Flow rate 2 gpm/sq.ft.

1. Dose introduced above the filter bed (Figure No 4-13) Table No. 19).

   Time taken to attain 7 ft. head loss = 20 hours.

2. Dose introduced in the bed. (Figure No. 4.13 Table No. 20)

   Time taken to attain 7 ft. head loss = 32 hours.

4.3 EVALUATION OF GT FACTOR IN THE FILTER BED:

The rate of floc formation and the strength of the floc depends upon the GT factor. The GT factor for the alum doses of 10 and 60 mg/l have be calculated. The values are given below.

Alum dose 10 mg/l

Dose added to influent water

Flow rate 2 gpm/sq.ft.

Water temperature 25°C. $\mu = 1.9 \times 10^{-5}$ lbs sec/ft^2

Table No. 4.1

Layer	Head loss h in ft.	Length of bed, l in ft.	$P=\frac{QWH}{alp}$	$G=\sqrt{P/\mu}$ sec^{-1}	GT
0- 4"	1.85	0.33	4.7	4.95×10^2	308×10^2
4- 8"	0.65	0.33	1.65	2.95×10^2	183×10^2
8-12"	0.4	0.33	1.015	2.31×10^2	144×10^2
12-16"	0.3	0.33	0.764	2×10^2	124.5×10^2
16-20"	0.2	0.33	0.504	1.63×10^2	103×10^2
20-24"	0.05	0.33	0.127	0.82×10^2	51×10^2
24-28"	0.05	0.33	0.127	0.82×10^2	51×10^2
28-30"	Negligible	-	-	-	-

Average value of $\bar{G} = 1.91 \times 10^2$

Dose added in the bed 3" from top

0- 4"	0.75	0.33	1.9	3.16×10^2	197×10^2
4- 8"	0.45	0.33	1.14	2.45×10^2	152×10^2
8-12"	0.3	0.33	0.755	2×10^2	124.5×10^2
12-16"	0.25	0.33	0.638	1.84×10^2	114.5×10^2
16-20"	0.5	0.33	0.127	0.82×10^2	51×10^2

The value of G is negligible for bottom layers

Average value of $G = 1.03 \times 10^2$

Dose 60 mg/l. Dose added in the bed

0- 4"	0.9	0.33	2.28	3.46×10^2	216×10^2
4- 8"	0.7	0.33	1.78	3.08×10^2	191.5×10^2
8-12"	0.45	0.33	1.14	2.45×10^2	152×10^2
12-16"	0.35	0.33	0.865	2.13×10^2	132.5×10^2
16-20"	0.2	0.33	0.508	1.64×10^2	102×10^2
22-24"	0.05	0.33	0.127	0.82×10^2	51×10^2

The value of G is negligible for bottom layers from 24-32".
Average value of $G = 1.7 \times 10^2$

Layers	Head loss h in ft.	Length of bed l in ft.	$P=\frac{QWH}{alp}$	$G = \sqrt{P/\mu}$ $sec.^{-1}$	GT
Dose 60 mg/l. Dose added to influent water					
0– 4"	4.5	0.33	11.5	7.78×10^2	485×10^2
4– 8"	1.5	0.33	3.8	4.46×10^2	278×10^2
8–12"	0.75	0.33	1.9	3.16×10^2	196.5×10^2
12–16"	0.45	0.33	1.14	2.45×10^2	152×10^2
16–20"	0.25	0.33	0.635	1.83×10^2	113.5×10^2
20–24"	0.15	0.33	0.380	1.41×10^2	87.6×10^2
24–28"	0.1	0.33	.253	1.15×10^2	71.5×10^2
28–32"	0.05	0.33	0.127	0.82×10^2	51×10^2

Average value of G = 2.88×10^2

In the above expressions;

G = Root mean square velocity gradient.

P = Power dessipation/unit volume in ft.labs/sec/cu.ft.

μ = Viscosity of fluid.

Q = Discharge.

p = Porosity of sand bed.

W = Specific weight of water.

h = Head loss.

A = Area of cross section through which fluid is passing.

l = length of chamber.

T = Time for which fluid remains in the chamber.

Figure No 4·1

Graph Between Turbidy & Absorbance
Wave Length 390 mu

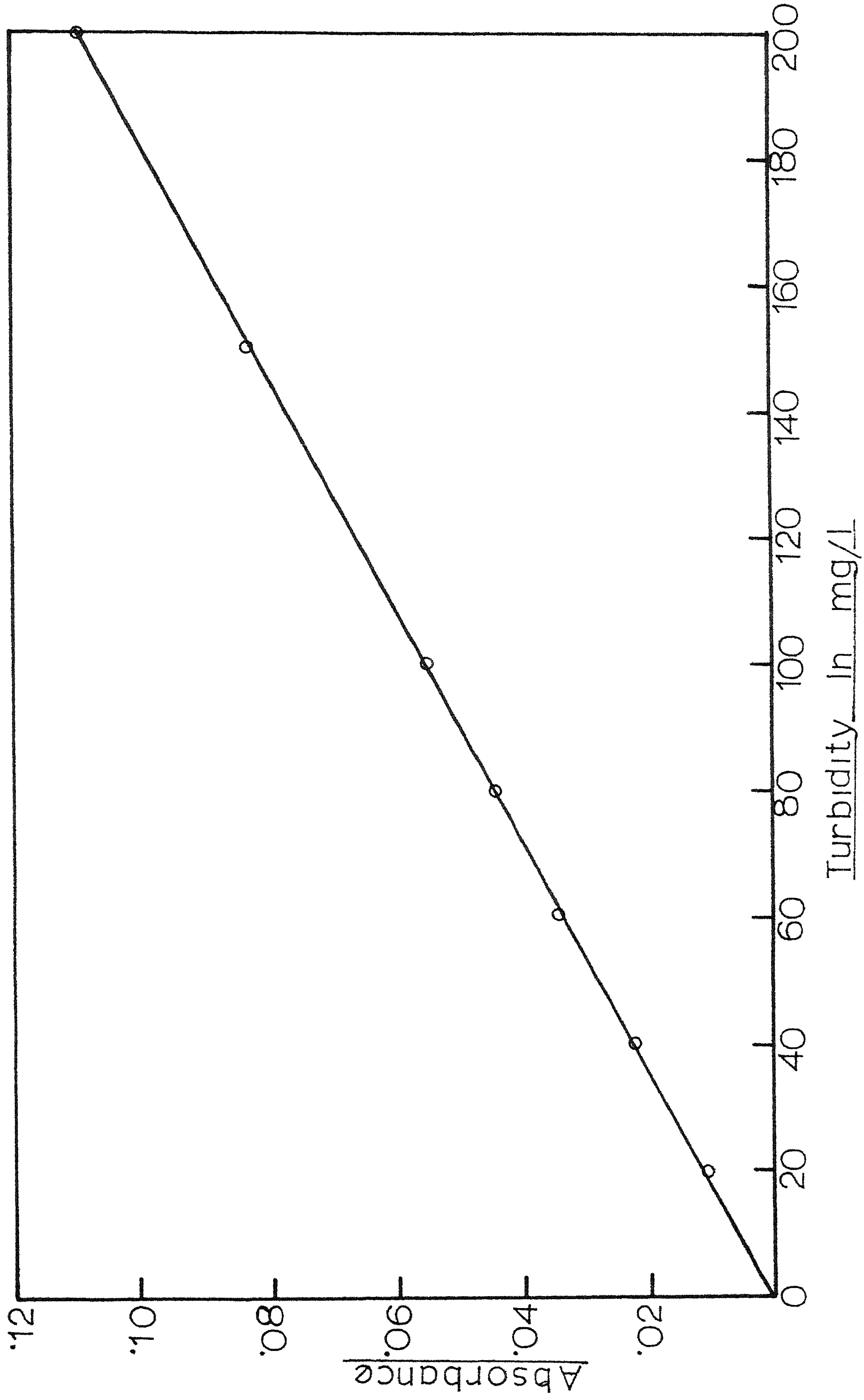
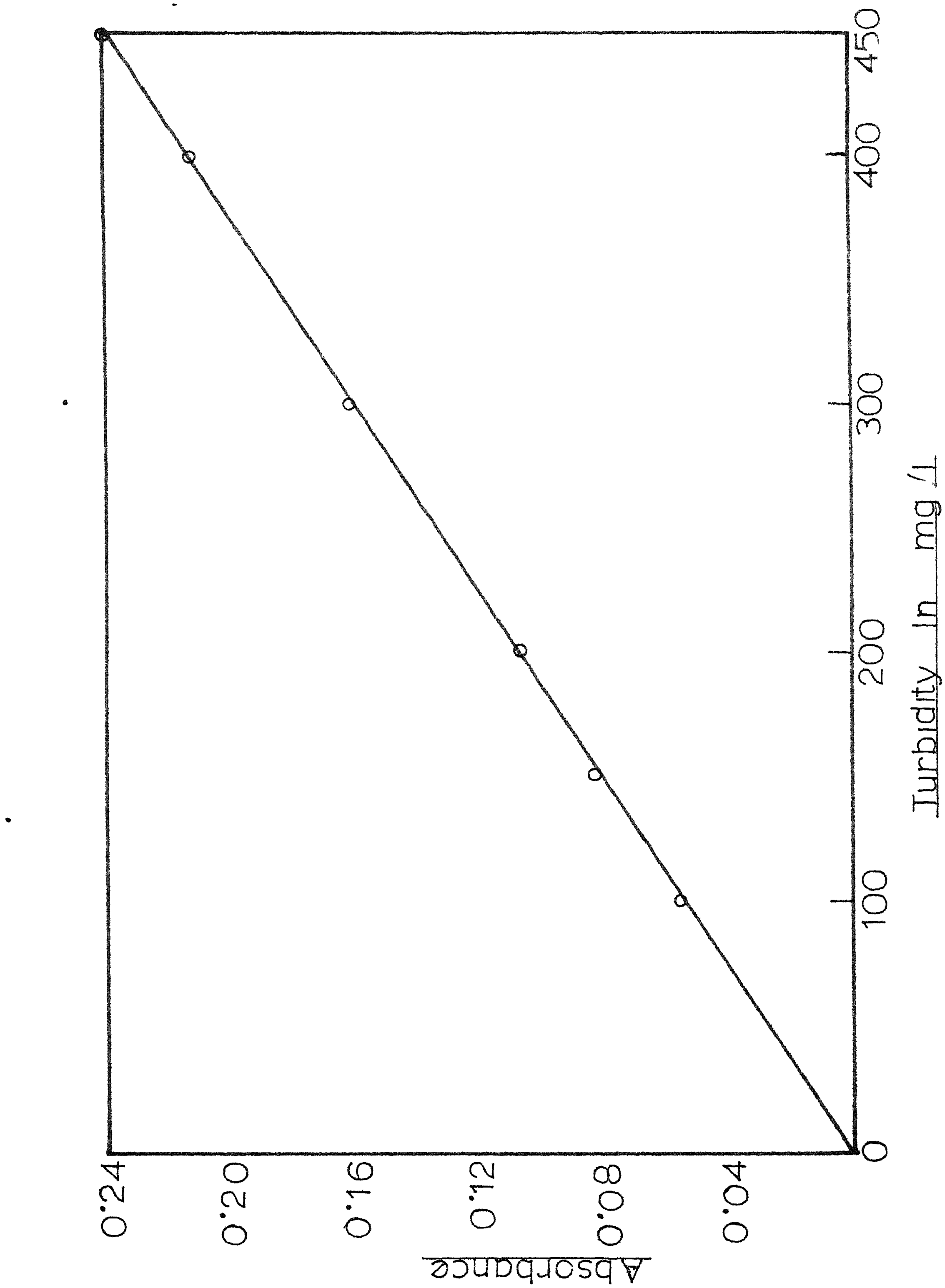


Figure No 4·2

Graph Between Turbidity & Absorbance

Wave Length 390 mu



Sieve Analysis Of Sand

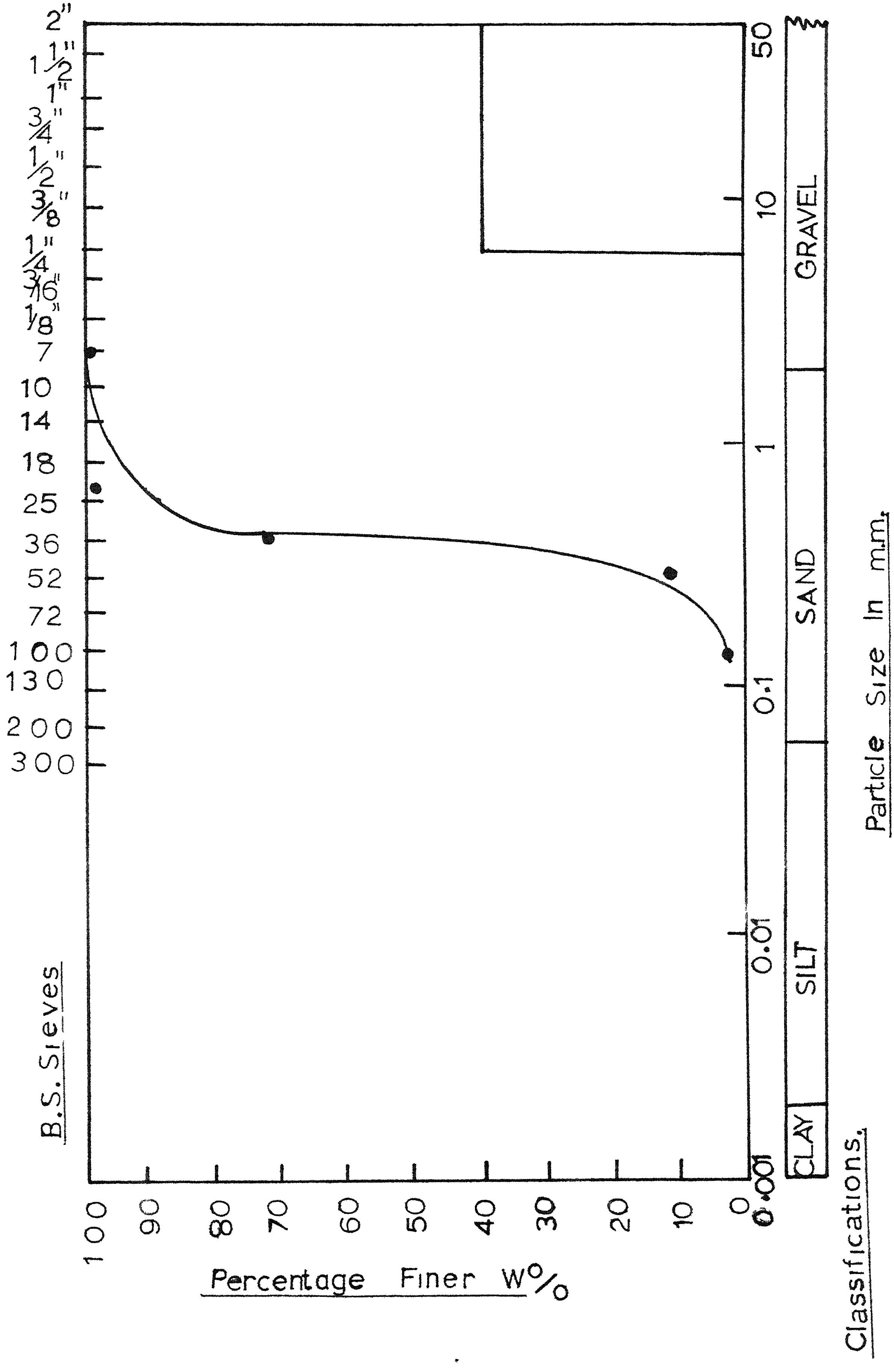


Figure No – 4·4

Optimum Dose Of Alum By Jar Test

Initial Turbidity 100 mg/l

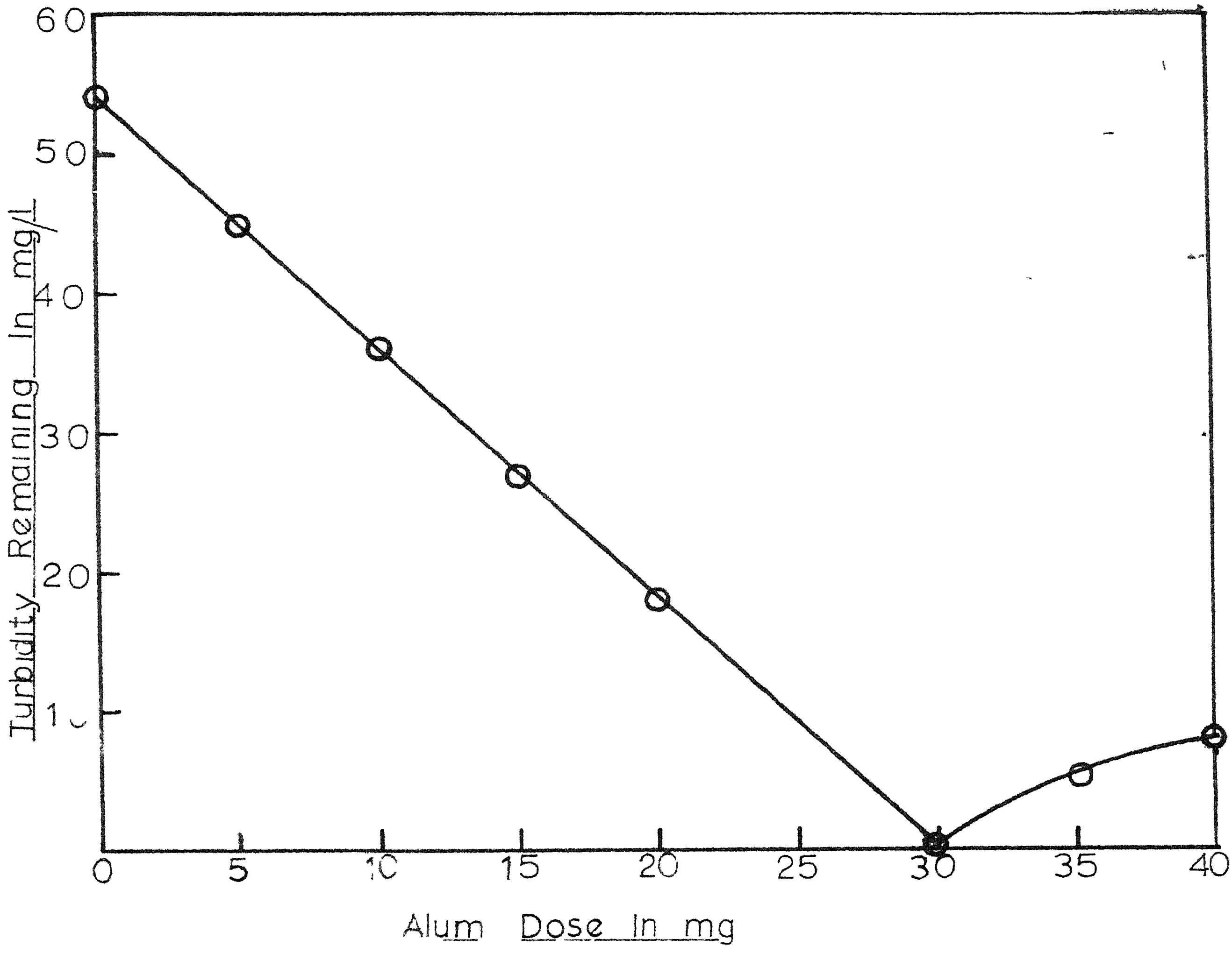
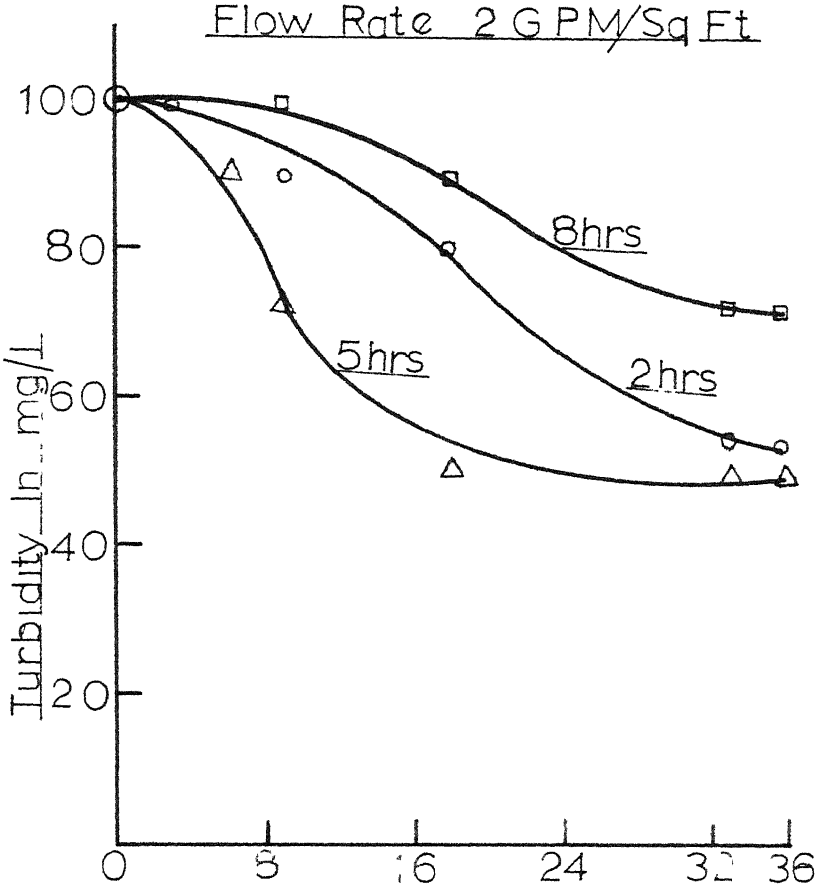


Figure No- 4.5

Filter Run Without Alum Dose

Flow Rate 2 GPM/Sq Ft



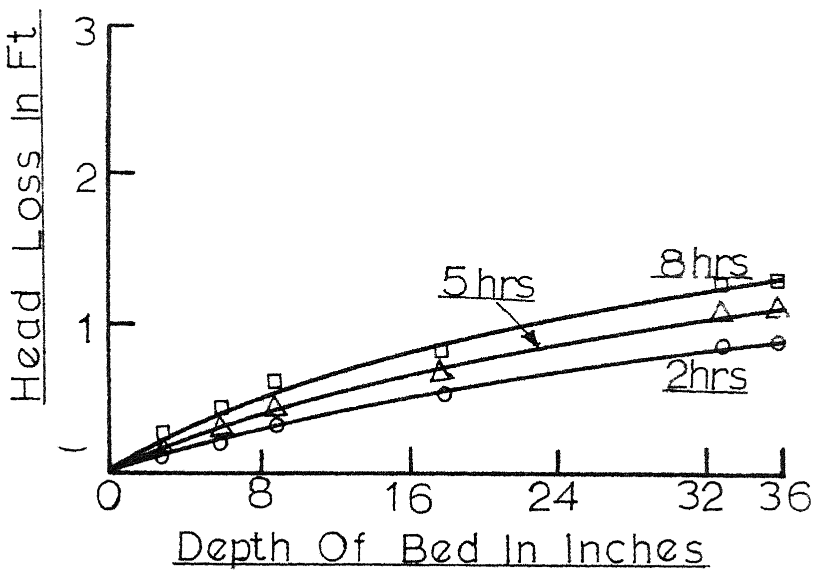
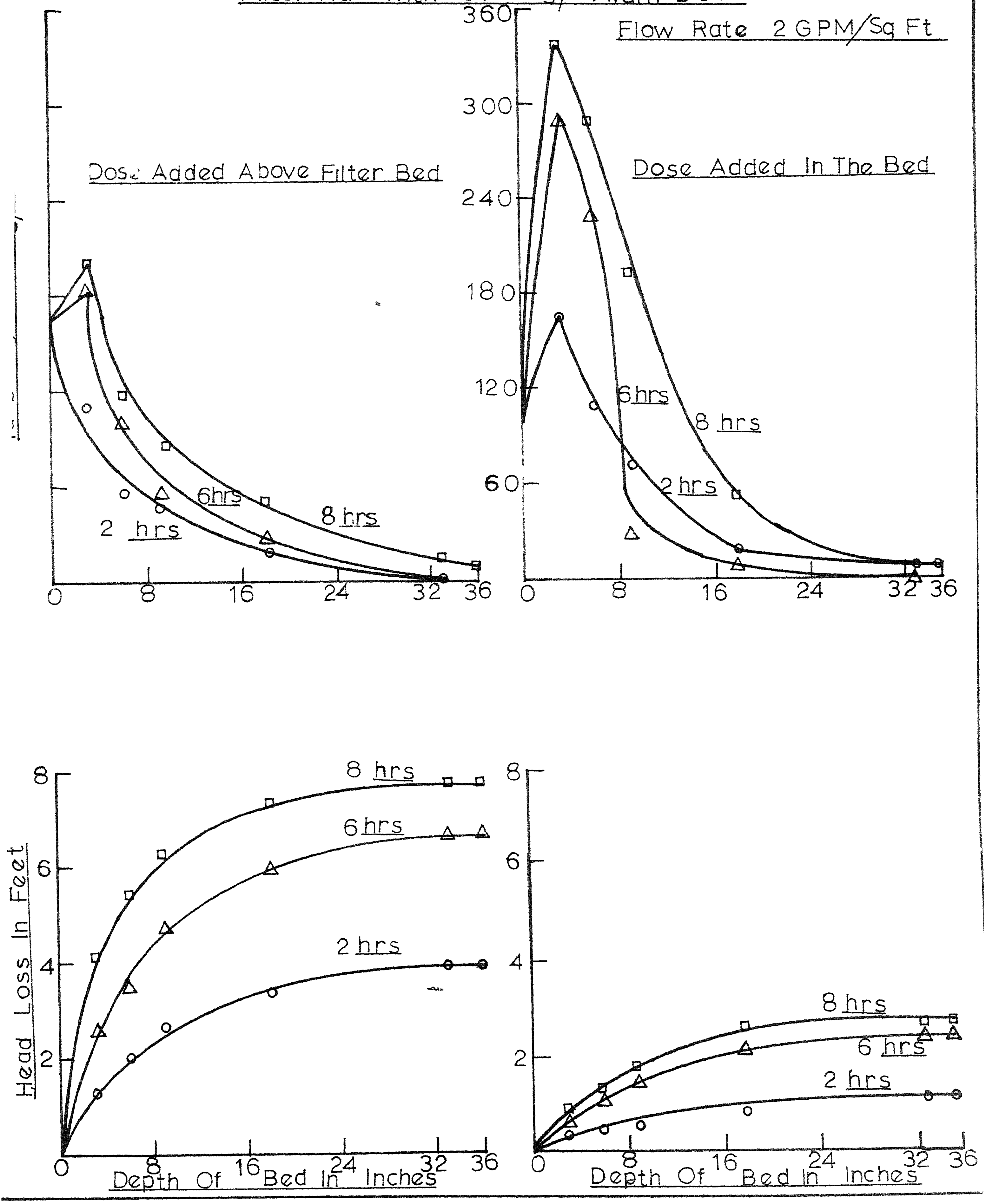


Figure No-4·6

Filter Run With 60 mg/l Alum Dose



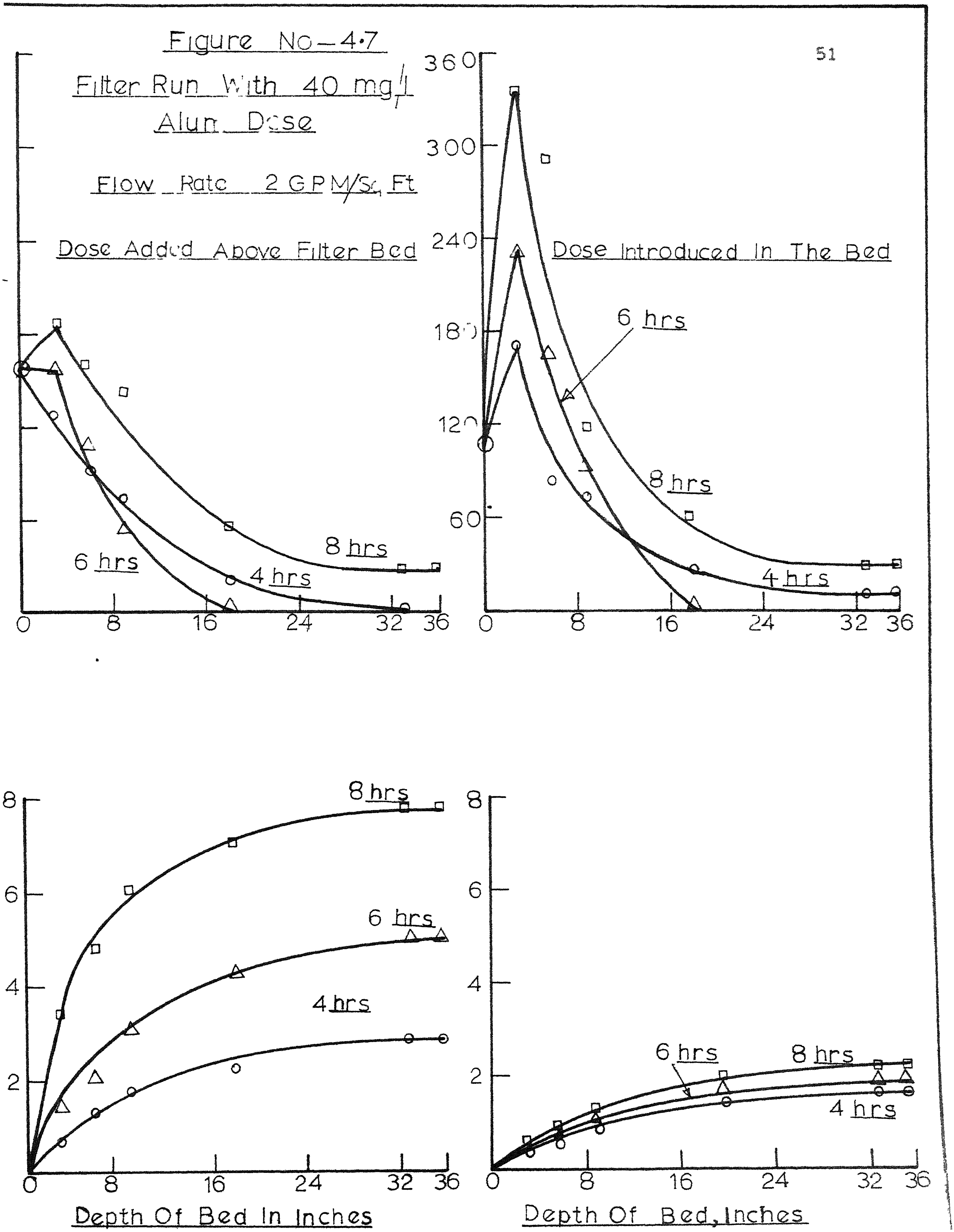


Figure No—4·7
Filter Run With 40 mg/l Alum Dose
Flow Rate 2 GPM/Sq Ft
Dose Added Above Filter Bed
Dose Introduced In The Bed
360
300
240
180
120
60
0
8
16
24
32
36
8 hrs
6 hrs
4 hrs
2
4
6
8
Depth Of Bed In Inches
Depth Of Bed, Inches

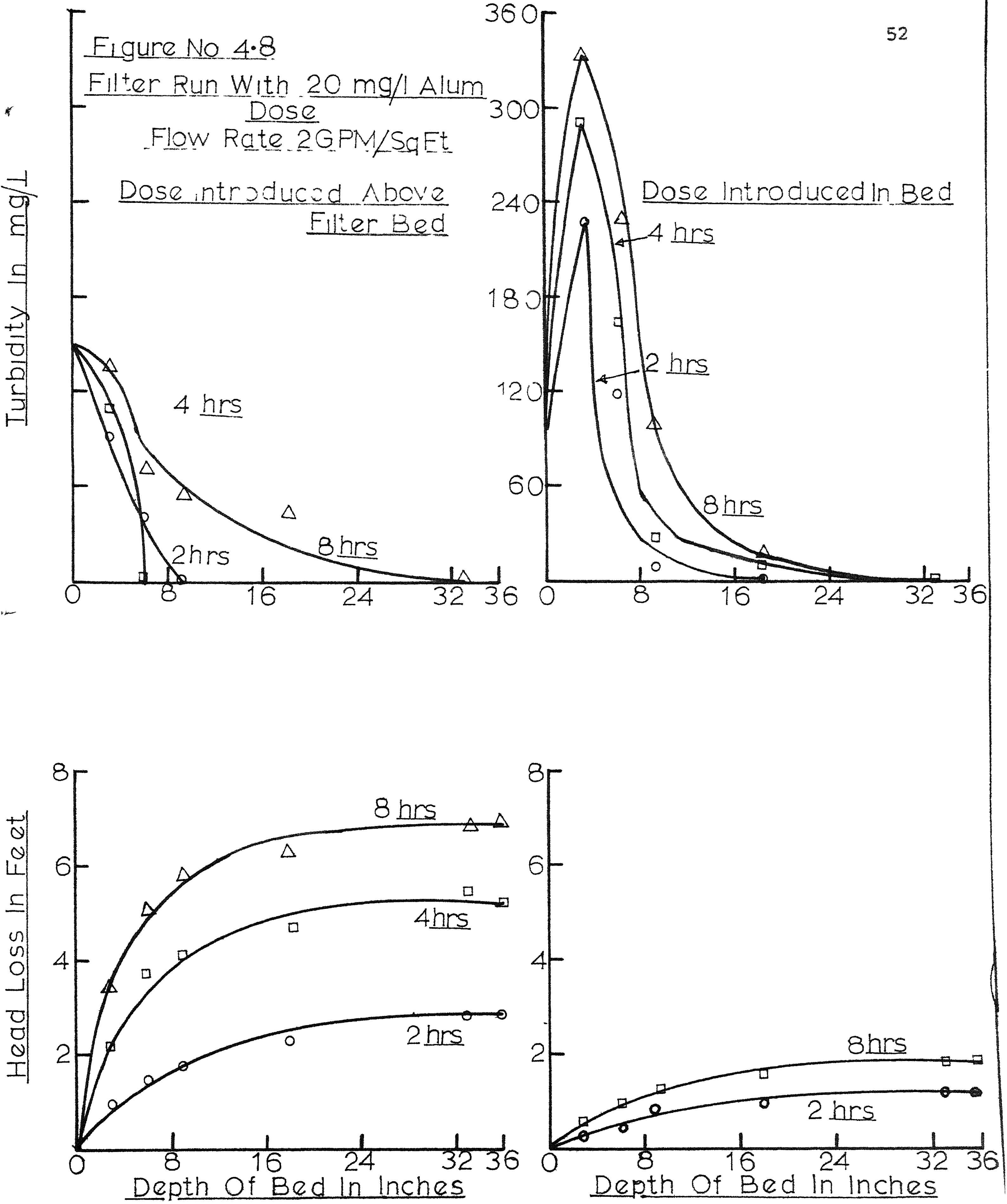


Figure No 4·8
Filter Run With 20 mg/l Alum Dose
Flow Rate 2GPM/SqFt
Dose introduced Above Filter Bed
Dose Introduced In Bed
Turbidity In mg/L
4 hrs
2 hrs
8 hrs
Head Loss In Feet
Depth Of Bed In Inches
0
8
16
24
32
36
60
120
180
240
300
360
2
4
6

Figure No—4·9

Filter Run With 10 mg/l Alum Dose

Flow Rate 2 gpm/Sq Ft

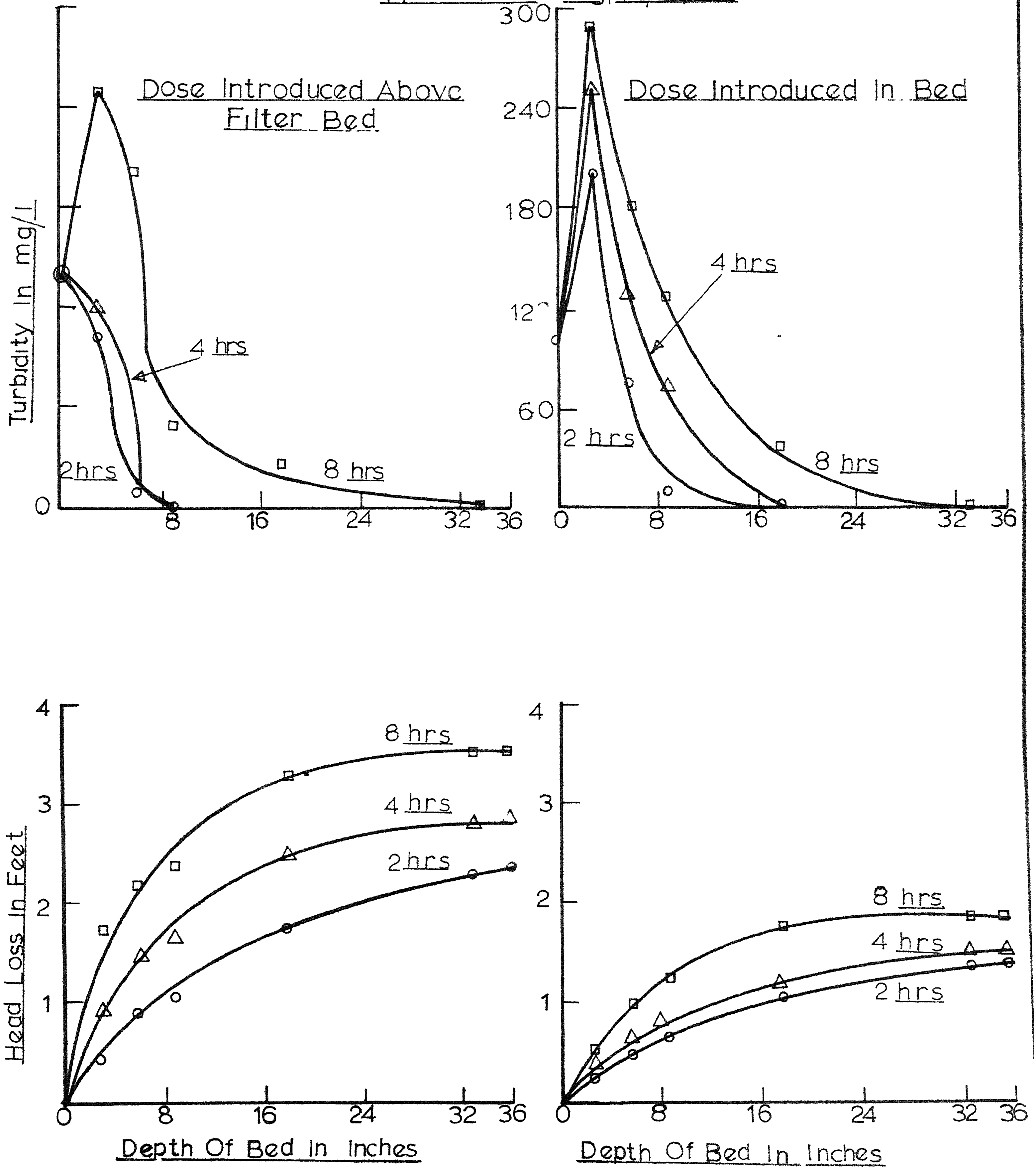


Figure No — 4·10

Filter Run With 5 mg/l Alum Dose

Flow Rate 2 GPM/Sq Ft

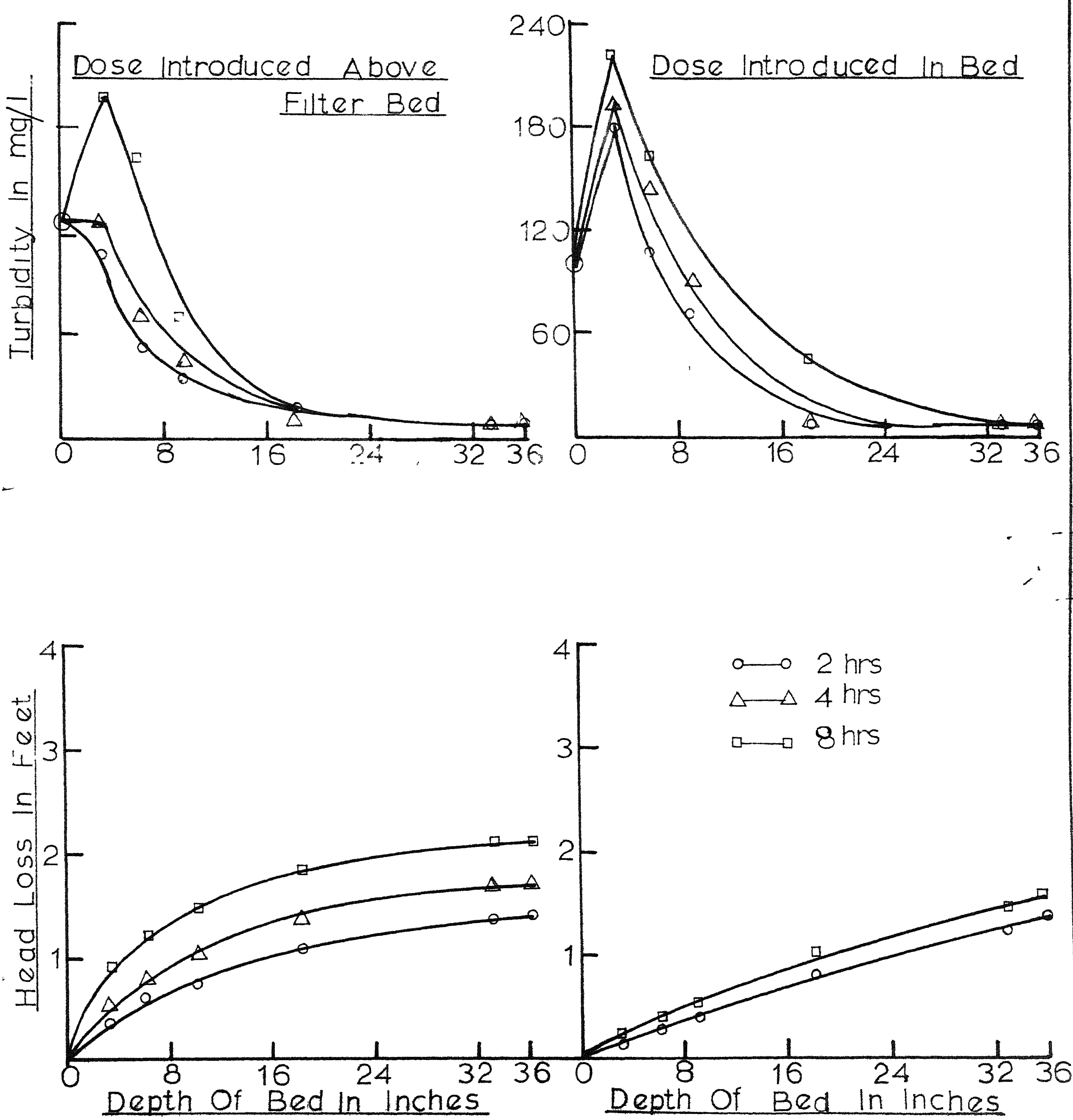


Figure No – 4·11

Filter Runs With Alum Dose Introduced At Different Depths

Flow Rate 2GPM/Sq Ft. Alum Dose 10 mg/l

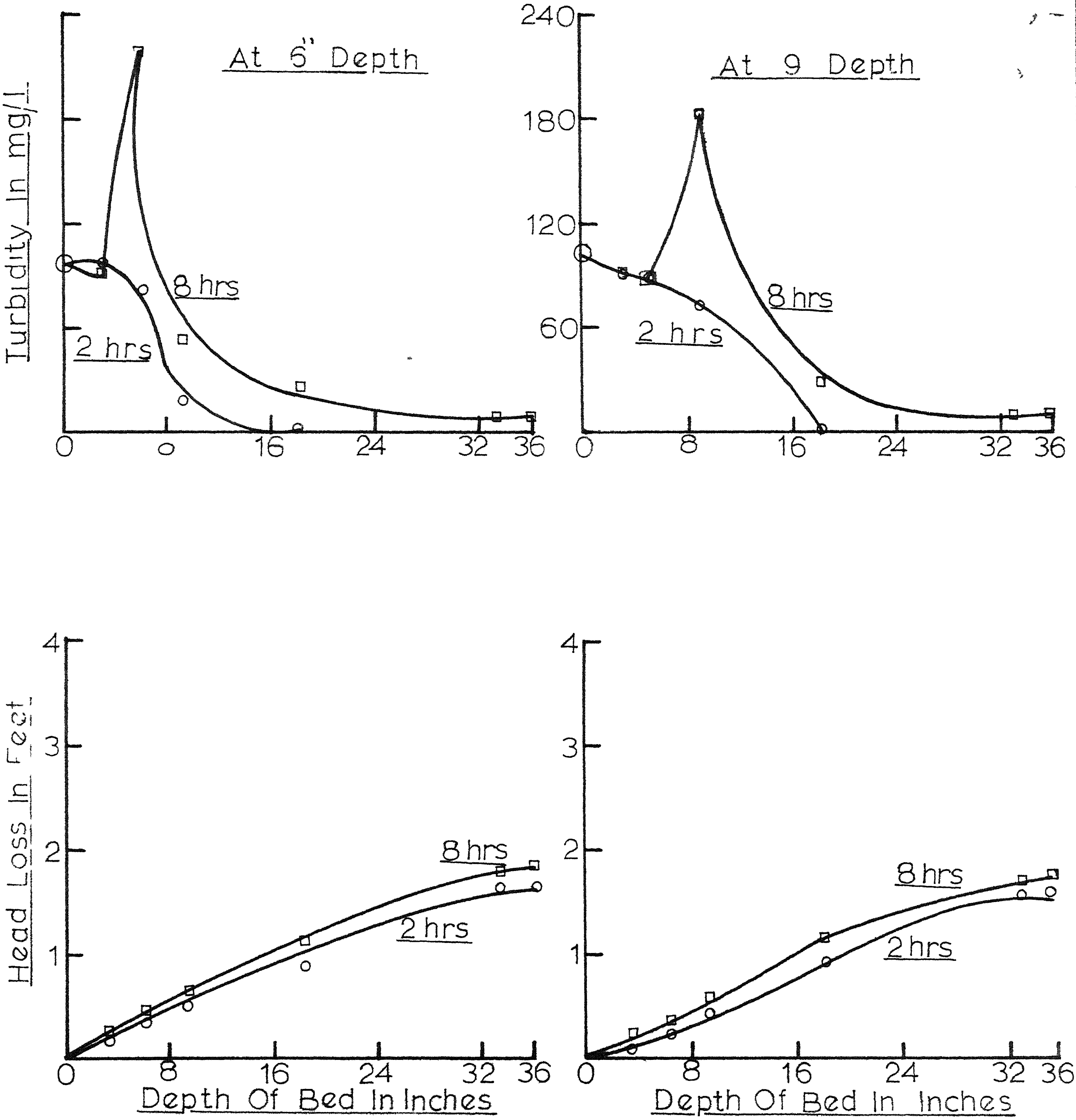


Figure No—4.12

Filter Runs At Increased Flow Rates

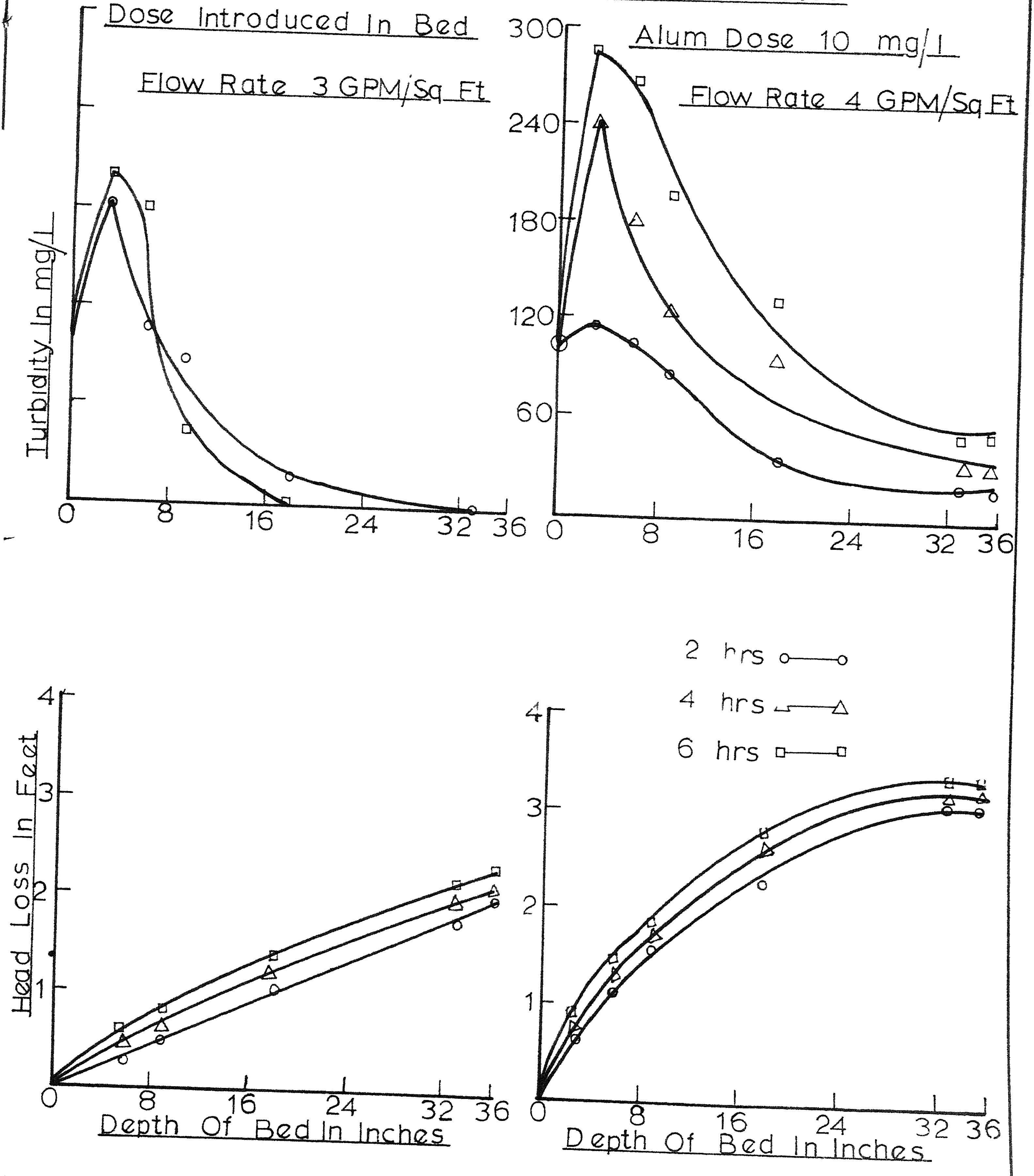


Figure No-4.13

Filter Run With 10 mg/l Alum Dose

Flow Rate-2 GPM/Sq ft

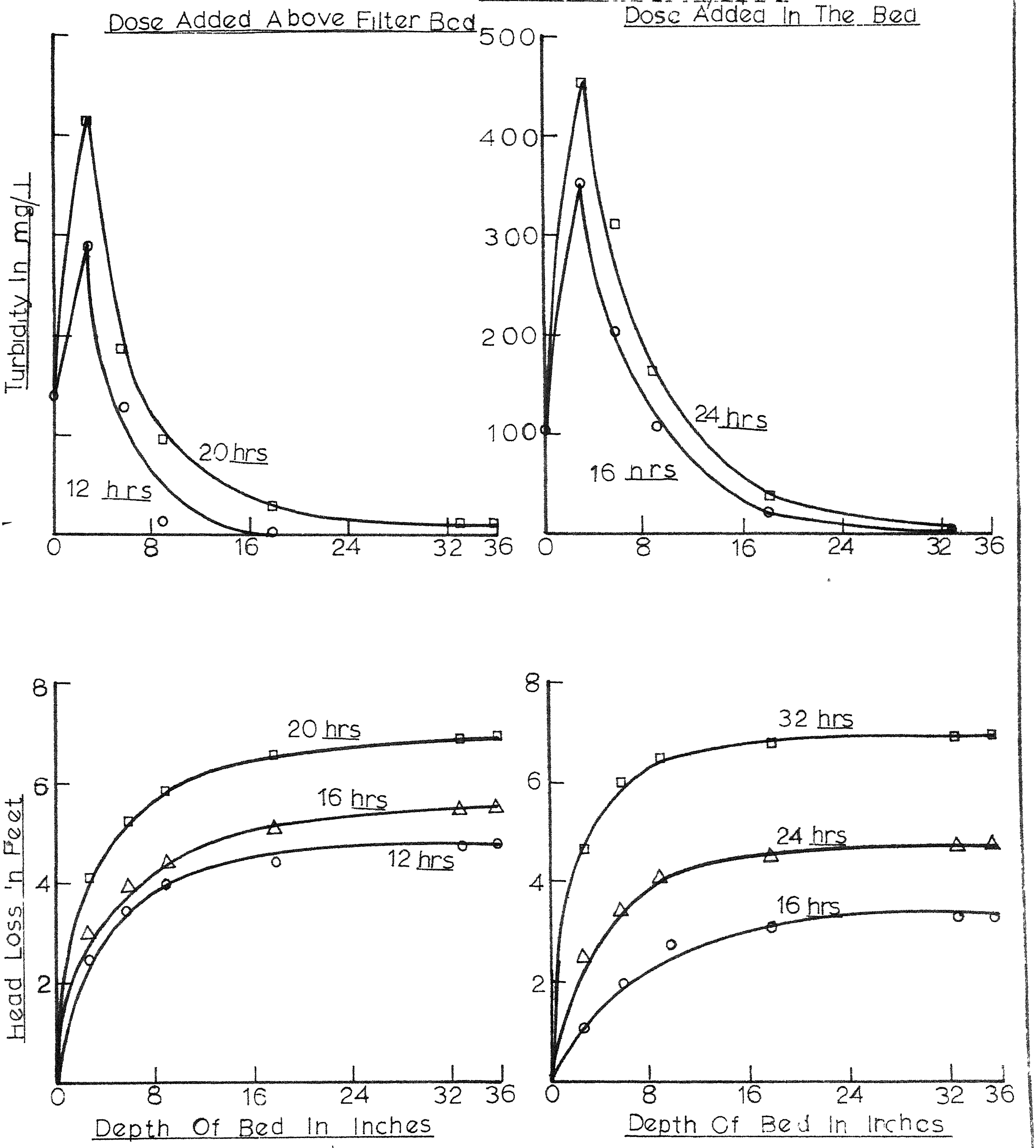
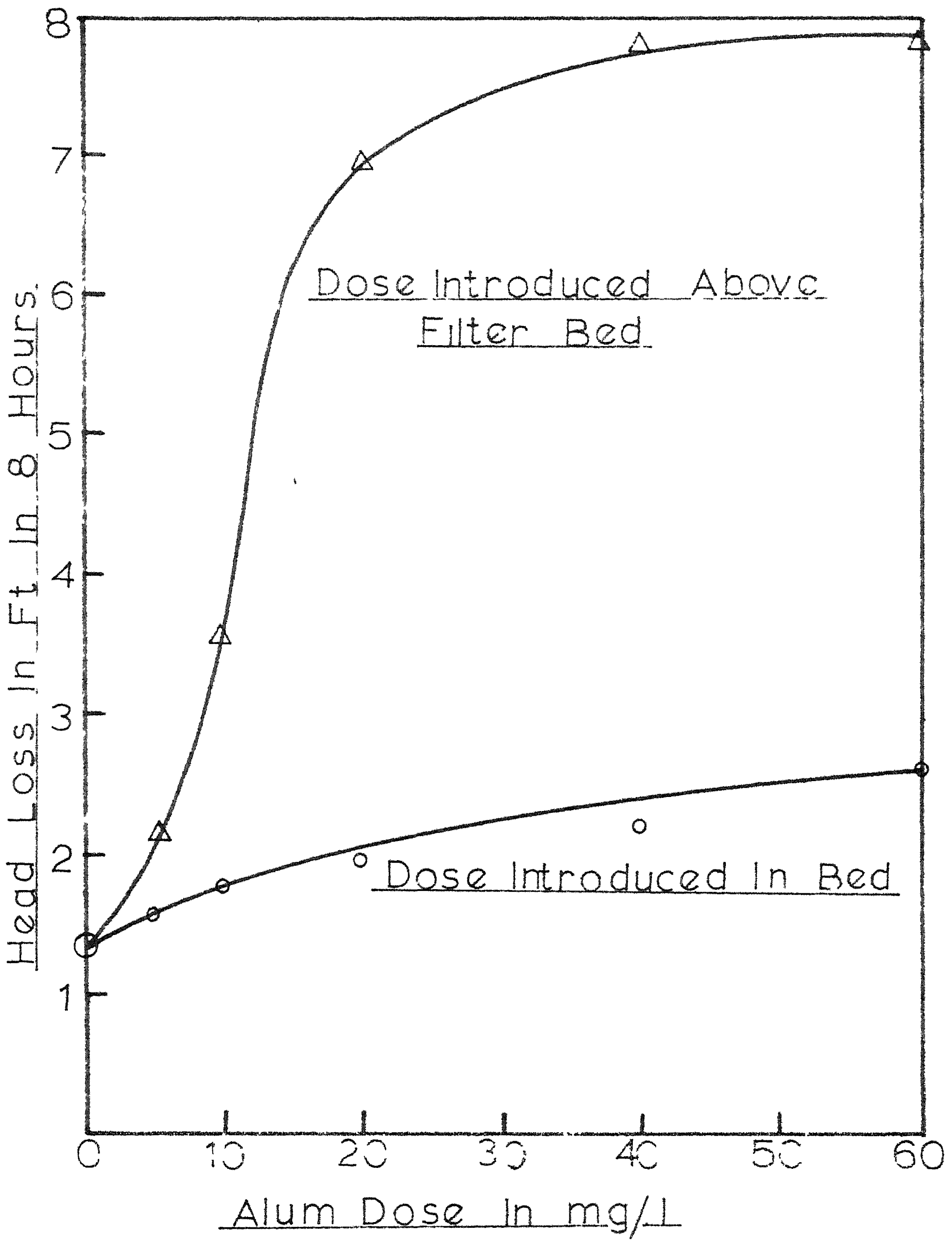


Figure No 4.14

Head Loss In 8 Hours For Different Alum Doses



CHAPTER V

DISCUSSIONS

5.1 FILTER RUNS WITHOUT COAGULANT AID

Filter runs without alum dose resulted in only 55% removal of turbidity. The building of head loss was relatively small and more or less evenly distributed throughout the filter bed. The removal of turbidity was also uniformly distributed throughout the bed. The effluent quality started deteriorating after 5 hours of the filter run. From these observations it seems that the straining mechanism was not predominent in this case and the removal of turbidity took place because of the electrokinetic phenomenon, interception, diffusion and gravitational settling.

This type of result has been reported by many other workers also. Ives (11) and Ghosh (23) have shown that insignificant removal of clay turbidity was obtained when no coagulant dose was used. The head loss build up was relatively small. The particles penetrated in the filter bed and the filtrate quality deteriorated with time.

Eric Davis and J.A. Borchardt (31) while working on the filtration of particulate matter in the form of algal cells and activated carbon, have also shown that insignificant removal was obtained in the absence of coagulant dose and the filtrate quality deteriorated with time.

These results indicate that the filter can be run for longer time without needing back wash, but the efficiency of removal will be so much less that the importance of filteration as an operation will be lost.

5.2 INTRODUCTION OF ALUM DOSE TO INFLUENT WATER 3" ABOVE THE BED:

1. The optimum dose of alum for standard jar test for 100 mg/l of turbidity was found to be 60 mg/l. When this dose was added above the filter bed to influent water 100% removal of turbidity was obtained. The head loss build up was very rapid and 7.8 ft. of head loss occured in 8 hours. Most of the head loss occurred in the top layers of the bed and most of the turbidity was also removed in the top layers. (Fig. No. 4.6) Clogging of the top layers indicate that there was a tendency of mat formation on the top of the filter bed and the removal mechanism effective in this case was mechanical straining. This also indicates a higher strength of the flocs formed. S.L. Hannel et al (12) have shown that an excessive floc strength caused bulk of the floc to remain within the top layers of the filter and the tendency for break through was smaller.

If the same rate of flow was maintained throughout, the hydraulic gradient incresed at the top layers, may be due to reduced porosity of the top layers. This causes the floc to penetrate to the next layer if the hydraulic gradient exceeds the floc strength. This phenomenon of penetration

of floc can be seen from fig. no. 4.6. The concentration of particles increseswith time at a depth of 3" from top

It appears from the excessive turbidity in the top layers,(Fig. No. 4.6 to 4.10) that in the case of flocculation the flocs formed incorporates significant quantities of water besides the suspension particles and the flocculant and the overall volume of floc clogging the filter may be much greater than the volume of the suspension particles.

Agarwal (16) in his studies also did experiments by introducing alum dose above the filter bed to the influent water. He concluded that if the flocculating agent like alum was introduced just ahead of the filter with no flocculation in the conventional sense. This incresed greatly the efficiency of filter at the start of the run. A rapid head loss occured in the top layers and the filter run had to be terminated 2½ hours after the start of the run for clay filtration due to excessive head loss build up.

With these observations obtained it can be concluded that the filter runs with a dose of 60 mg/l is not economical.

2. The values of the mean velocity gradient in the filter bed were found to be 288 sec^{-1} and 191 sec^{-1} for 60 and 10 mg/l alum doses respectively, when introduced to the influent water (Table No. 4.1). These velocity gradients are not sufficient for appreciable flocculation to take place in the filter bed. These values are higher than the values obtained for one in which alum was introduced in the bed.

P.C. Stein (20) computed the value of mean velocity gradient in the filter as 200 sec^{-1} and showed that no appreciable flocculation was taking place in the pores.

3. The other doses tried were 40, 20, 10 and 5 mg/l. 100% removal of turbidity was obtained by 40, 20 and 10 mg/l dose. As the alum dose is reduced the head loss development goes on reducing and becomes almost uniform as compared to the higher doses (Fig. No. 4.14) but the tendency of removal in the upper layers remains dominant. The observations indicate that the size of the flocs formed reduces at lower doses and penetration of the flocs take place (Fig. No. 4.10). The mechanism of removal in this case seems to be straining and electrokinetic phenomenon. Coagulation in the filter may also be one of the mechanisms but the time for which the water remains in the filter is only about 9 minutes which is not sufficient for flocculation.

At lower doses almost the total depth of the bed is utilised in the removal of turbidity (Fig. No. 4.9, 4.10). This is required for the efficient working of the plant. Due to this the length of filter run significantly increases at lower doses.

4. The filter can be run for about 20 hours if a dose of 10 mg/l is introduced in to the influent water. The value of dh/dt increses with the time of the filter run (Fig. No 4.13). Because the clogging of the pores proceeds downward during operation, dh/dt increses

with time. The magnitude of dh/dt is proportional to the amount of suspended matter carried in to the filter (13).

The increase in loss of head between two points with time is solely due to the deposition of particles of turbid water in that portion of bed. These particles may contribute to the increased loss of head in the following ways.

a. By changing the specific surface which offers resistance to the flow of fluid.

b. By changing the porosity of the bed.

5.3 INTRODUCTION OF ALUM DOSE IN THE FILTER BED 3" FROM TOP.

1. The head loss development reduced considerably when alum was introduced in the filter bed. For a dose of 60 mg/l the head loss obtained was 2.67 ft as compared to 7.8 ft in the previous case, after 8 hours of filter run. This happened because of the better utilisation of the bed in removing turbidity. This also eliminated the formation of mat in the filter bed and caused more uniform head loss development.

The total head loss in the filter bed is the sum of the surface cake head loss and the head loss development in the bed. The head loss in the sand bed developes linearly because the rigid matrix of the sand bed prevents the compression of the deposited material. The production rate of water per filter run increses in this case because very few particles are removed in the surface cake. The head loss development curve for a dose of 5 mg/l becomes almost a straight line.

This shows that when the alum dose was introduced in the bed there was no mat formation and the removal of turbidity was throughout the bed.

2. The penetration of the flocs indicate that the size of the flocs formed reduces when alum dose is introduced in the bed. This may be due to fact that more time is required by alum to mix with water when alum is introduced in the bed. As the alum flows down wards it mixes with the turbid water and flocs are formed, where as in the previous case the alum dose was introduced in to the water and mixing was quick.

For effective and economical filtration the floc particles should be small enough to penetrate in to bed. This can be achieved by introducing smaller alum dose in to the filter bed.

3. The mechanism of removal predominant in these cases seems to be electrokinetic and coagulation in the bed. P.S. Stein (20) has shown that the removal of flocs within a bed is accomplished primarily by the contact of the floc particles with the surface of the sand grains or the floc already deposited. Contact is brought about primarily by the convergence of stream lines at contractions in pore channels and in the vicinity of curved surface of grains.

4. The values of mean velocity gradient for 60 and 10 mg/l of alum doses were found to be 170 sec^{-1} and 102 sec^{-1} (Table No. 4.1). These velocity gradients are also not sufficient to cause appreciable flocculation in the bed.

5. The filter can be run for 32 hours with an alum dose of 10 mg/l introduced in the filter bed. In this way the filter run can be extended for 12 hours as compared to one in which alum dose was introduced to influent water. In this way production per run can be incresed by 1440 gallons/sq.ft of the filter bed. This will reduce the back wash water requirement. In this case also the dh/dt increases slightly with time of filter run. At the later stages of the filter run the head loss development curve becomes identical to that in which alum dose was introduced in the influent water. This indicates that at later stages the straining mechanism of removal becomes predominant due to the deposition of the flocs in the upper layers.

5.4 FILTER RUNS AT INCREASED FLOW RATES.

1. The head loss developement curve is almost a straight line for 3 gpm/sq.ft flow rate (Fig. No. 4.12). This is due to the utilisation of the total depth of the bed in removing the turbidity. The mechanism of removal in this case seems to be electrokinetic phenomenon.

With a flow rate of 4 gpm/sq.ft only 82% removal of turbidity was obtained. The total depth of bed was utilised in removing turbidity. At this flow rate it may be possible to remove 100% turbidity from water if the length of the filter bed is increased. Ives et al (11) have shown that if the flow rate is doubled the depth of bed

required also becomes twice the original depth to get the same effluent quality as obtained by the normal rate of flow.

With these observations it can be concluded that if the alum dose is introduced in the bed the production per filter run can be incresed further by incresing the flow rate to 3 gpm/sq.ft. without affecting the efficiency of removal.

5.5 INTRODUCTION OF ALUM DOSE AT DIFFERENT DEPTHS:

Introduction of alum dose at a depth of 6" from top seems to be better because in this case the head loss development was more uniform as compared to one in which alum was added at a depth of 3" from top. This shows that if alum is introduced at a depth of 6" from top it will take longer time to clog.

Introduction of alum dose at a depth of 9" from top will not be economical because the top 9" layer of sand bed will remain unused.

5.6 PRACTICAL IMPLICATIONS:

All the filter runs in which alum dose was added in the bed gave significantly higher removals without causing excessive head loss build up. If a proper method of introduction of alum in the bed is obtained such treatment would improve the efficiency of the filter significantly. This will be advantageous in one or more of the following ways.

1. The question of pretreatment will be solved. This will reduce the capital cost of construction of pretreatment plants.

2. Since the cost of water treatment depends mainly on cost of chemicals and the cost of back washing, the cost can be reduced considerably if alum dose is introduced in the bed. This will reduce the alum requirement and will produce long filter runs.

3. Incresed flow rates can be used taking the advantage of the incresed efficiency of removal and smaller head loss.

4. This method can also be applied in the filtration of Algal cells. Algal cells when flocculated clog the top layers of the filter bed, This causes difficulty in water treatment plants.

CHAPTER VI

CONCLUSIONS

1. Filtration of water without alum dose was not successful and seems to be less efficient in removing clay turbidity.

2. Introduction of alum dose above filter bed required 10 mg/l of alum dose to remove 100% turbidity. This was much smaller than the optimum alum dose required by Jar test. The head loss build up in the filter bed was more as compared to one in which alum dose was introduced in the filter bed. Only top layers of the bed was utilised in removing turbidity. This may prove to be economical as compared to the present practice of filtration but is less economical as compared to the other method discussed later.

3. Introduction of alum dose in the filter bed also required 10 mg/l of alum dose to remove 100% turbidity. The head loss development was considerably low due to the better utilisation of the filter bed. This produced longer filter runs and thus seems to be economical as compared to the present practice of filtration and the method discussed above.

4. Filter runs at incresed flow rate of 3 gpm/sq.ft was possible when alum dose was introduced in the filter bed without changing the efficiency of removal.

5. Introduction of alum dose in the bed at a depth of 6" and 9" from top of the bed produced almost the same amount of head loss in 8 hours as compared to one in which alum dose was introduced at a depth of 3". But introduction of alum dose at a depth of 6" from top may produce longer filter runs due to more uniform head loss development. The top layers of the bed remain unutilised in these cases.

6. Further work is required to find out a suitable method of introduction of alum in the filter bed.

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APPENDIX

TABLE NO. 1. Turbidity vs Absorbance for turbidity.

Wave length - 390 m u

Turbidity in mg/l	10	20	40	60	80	100
Absorbance	.005	.01	.02	.035	.045	.055
Turbidity in mg/l	150	200	300	400	450	
Absorbance	.085	.11	.16	.205	.24	

TABLE NO. 2 Sieve analysis of sand.

No.	B.S.SIEVE NO.	Weight retained in gms.	Cumulative wt. retained in gms.	% finer by weight
1	7	0	0	100
2	25	0	0	100
3	36	136.5	136.5	72.6
4	52	310.5	447.0	10.6
5	100	43.0	490.0	2

TABLE NO. 3 Optimum Alum dose by Jar test.

No.	Alum dose mg/l	Absorbance of supernatant	% Turbidity remaining
1	0	0.03	54
2	5	0.025	45
3	10	0.02	36
4	15	0.015	27
5	20	0.01	0
6	30	0	0
7	35	0.0025	5
8	40	0.005	8

TABLE NO. 4 Filter run without alum dose.

Time from start of run in hrs	Turbidity in mg/l at depths							Head loss ft at depths					
	3	6	9	18	33	36	eff.	3	6	9	18	33	36
1	100	90	90	80	72	72	72	.15	.2	.3	.50	.82	.83
2	100	90	90	80	54	54	54	.15	.2	.3	.525	.87	.87
3	100	90	90	54	54	54	54	.18	.27	.35	.615	.87	.88
4	100	90	90	54	54	54	54	.19	.28	.4	.635	.98	1.0
5	100	90	72	45	45	45	45	.2	.3	.45	.67	1.1	1.1
6	100	80	72	63	54	54	54	.24	.30	.52	.685	1.15	1.15
7	100	100	100	100	63	63	63	.27	.42	.56	.715	1.17	1.2
8	100	100	100	90	72	72	72	.3	.45	.6	.8	1.28	1.30

TABLE NO. 5 Filter run with 60 mg/l Alum dos. Dose added 3" above filter bed. Flow rate 2 gpm/sq.ft.

1	90	53	53	27	18	18	18	.8	1.6	2.25	2.3	2.66	2.77
2	109	54	45	18	0	0	0	1.3	2.0	2.65	3.38	3.80	3.99
3	127	54	45	18	0	0	0	1.7	2.3	3.2	3.69	4.4	4.4
4	145	54	27	0	0	0	0	2.0	2.7	3.7	4.58	5.01	5.01
5	164	54	18	0	0	0	0	2.4	3.1	4.3	5.2	5.96	5.98
6	183	100	54	27	0	0	0	2.6	3.5	4.7	5.9	6.68	6.7
7	200	100	72	72	0	0	0	3.2	4.3	5.5	5.97	6.91	6.91
8	200	118	90	54	18	8	8	4.1	5.5	6.3	7.41	7.8	7.8

TABLE NO.6 Filter run with 40 mg/l Alum dose. Dose added 3" above filter bed. Flow rate 2 gpm/sq.ft.

Time from start of run in hrs	Turbidity in mg/l at depths							Head loss ft. at depths					
	3	6	9	18	33	36	eff	3	6	9	18	33	36
1	109	90	72	36	27	27	27	0.3	0.4	0.5	0.72	1.13	1.46
2	109	100	90	18	8	8	8	0.4	0.5	0.7	1.17	1.86	1.89
3	127	109	90	18	8	8	8	0.6	0.9	1.2	1.72	2.48	2.51
4	127	90	72	18	0	0	0	0.6	1.25	1.7	2.09	2.74	2.78
5	127	109	90	0	0	0	0	0.9	1.50	2.1	3.14	3.8	3.8
6	155	109	90	0	0	0	0	1.3	2.0	3.0	4.28	4.98	5.0
7	164	127	109	27	27	27	27	2.4	3.2	4.4	6.31	7.18	7.18
8	183	164	155	54	27	27	27	3.3	4.8	6.0	7.01	7.74	7.8

TABLE NO. 7 Filter run with 20 mg/l Alum dose. Dose added 3" above filter bed. Flow rate 2 gpm/sq.ft.

1	90	18	0	0	0	0	0	1.04	1.26	1.34	1.62	2.35	2.42
2	90	18	0	0	0	0	0	1.1	1.56	1.69	2.05	2.82	2.84
3	108	0	0	0	0	0	0	1.89	2.99	3.13	3.49	4.34	4.4
4	108	0	0	0	0	0	0	2.12	3.74	4.08	4.38	5.16	5.16
5	118	18	0	0	0	0	0	2.29	4.39	4.52	4.87	5.71	5.74
6	137	45	0	0	0	0	0	2.7	4.97	5.13	5.44	6.24	6.27
7	137	67	53	45	0	0	0	3.0	5.1	5.4	5.7	6.55	6.55
8	137	67	53	45	0	0	0	3.4	5.21	5.82	6.09	6.87	6.94

TABLE NO. 8 Filter run with 10 mg/l Alum dose. Dose added 3" above filter bed. Flow rate 2 gpm/sq.ft.

Time from Start of run in hrs	Turbidity in mg/l at depths							Head loss ft. at depths					
	3	6	9	18	33	36	eff	3	6	9	18	33	36
1	100	8	0	0	0	0	0	0.21	0.34	0.42	0.83	1.74	1.78
2	100	8	0	0	0	0	0	0.4	0.89	1.02	1.75	2.3	2.31
3	108	8	0	0	0	0	0	0.63	1.14	1.26	2.0	2.58	2.60
4	118	8	0	0	0	0	0	0.83	1.44	1.59	2.50	2.81	2.82
5	250	118	0	0	0	0	0	1.3	1.63	1.75	2.7	2.98	2.99
6	250	118	0	0	0	0	0	1.4	1.77	1.93	2.8	2.10	3.11
7	250	118	0	0	0	0	0	1.66	1.95	2.1	3.0	3.25	3.27
8	250	200	45	27	0	0	0	1.75	2.16	2.34	3.3	3.5	3.52

TABLE NO. 9 Filter run with 5 mg/l Alum dose. Dose added 3" above filter bed. Flow rate 2 gpm/sq.ft.

1	45	27	18	18	18	18	18	0.31	0.47	0.61	0.99	1.27	1.28
2	108	54	18	8	8	8	8	0.37	0.59	0.73	1.09	1.35	1.36
3	108	65	27	8	8	8	8	0.43	0.72	0.9	1.26	1.53	1.55
4	108	73	27	8	8	8	8	0.55	0.77	1.01	1.38	1.65	1.66
5	108	82	45	8	8	8	8	0.63	0.81	1.09	1.44	1.7	1.71
6	108	90	45	8	8	8	8	0.72	0.96	1.16	1.49	1.73	1.74
7	108	90	45	8	8	8	8	0.78	1.1	1.42	1.79	2.06	2.07
8	108	90	54	8	8	8	8	0.92	1.24	1.46	1.84	2.10	2.11

TABLE NO. 10 Filter run with 60 mg/l alum dose. Dose introduced in bed 3" from top. Flow rate 2 gpm/sq.ft.

Time from start of run in hrs	Turbidity in mg/l at depths							Head loss ft. at depths					
	3	6	9	18	33	36	eff	3	6	9	18	33	36
1	155	36	27	18	18	18	18	0.25	0.3	0.42	0.74	0.97	1.01
2	164	109	72	18	8	8	8	0.3	0.33	0.46	0.78	1.01	1.01
3	200	109	18	0	0	0	0	0.32	0.36	0.49	0.78	1.01	1.02
4	230	145	10	0	0	0	0	0.41	0.46	0.79	0.94	1.21	1.22
5	290	145	18	0	0	0	0	0.55	0.96	1.3	1.85	2.28	2.37
6	290	230	27	8	0	0	0	0.75	1.12	1.45	2.04	2.44	2.43
7	335	290	36	27	10	10	10	0.8	1.21	1.52	2.13	2.51	2.58
8	335	290	72	53	10	10	10	0.82	1.21	1.55	2.52	2.54	2.61

TABLE NO. 11 Filter run with 40 mg/l Alum dose. Dose introduced in bed 3" from top. Flow rate 2 gpm/sq.ft.

1	155	45	36	18	18	18	18	0.23	0.35	0.72	1.24	1.27	1.3
2	155	82	72	27	8	8	8	0.27	0.35	0.77	1.25	1.31	1.33
3	164	82	72	18	8	8	8	0.29	0.37	0.8	1.35	1.41	1.45
4	200	90	36	0	0	0	0	0.32	0.39	0.83	1.52	1.56	1.65
5	200	109	82	0	0	0	0	0.34	0.47	0.89	1.57	1.61	1.73
6	230	164	90	0	0	0	0	0.37	0.54	0.94	1.66	1.71	1.79
7	290	200	90	0	0	0	0	0.41	0.58	1.0	1.75	1.80	1.85
8	335	290	118	63	27	27	27	0.54	0.74	1.22	1.99	2.13	2.2

TABLE NO. 12 Filter run with 20 mg/l Alum dose. Dose introduced in bed 3" from top. **Flow rate 2 gpm/sq.ft.**

Time from start of run in hrs	Turbidity in mg/l at depths							Head loss ft. at depths					
	3	6	9	18	33	36	eff	3	6	9	18	33	36
1	155	73	8	0	0	0	0	0.25	0.37	0.70	0.92	1.14	1.16
2	230	127	8	0	0	0	0	0.3	0.42	0.77	1.0	1.21	1.21
3	230	164	27	8	0	0	0	0.36	0.47	0.83	1.07	1.33	1.34
4	290	164	27	8	0	0	0	0.4	0.55	0.87	1.12	1.34	1.35
5	290	179	27	8	0	0	0	0.45	0.71	0.94	1.24	1.46	1.46
6	335	183	36	8	0	0	0	0.48	0.9	1.0	1.41	1.66	1.66
7	335	192	63	8	0	0	0	0.50	0.93	1.14	1.52	1.77	1.77
8	335	230	102	8	0	0	0	0.54	1.06	1.27	1.77	1.91	1.94

TABLE NO. 13 Filter run with 10 mg/l Alum dose. Dose introduced in bed 3" from top. Flow rate 2 gpm/sq.ft.

1	200	73	0	0	0	0	0	0.21	0.35	0.47	.084	1.14	1.17
2	200	73	8	0	0	0	0	0.26	0.48	0.66	1.02	1.35	1.41
3	250	36	27	0	0	0	0	0.33	0.57	0.71	1.1	1.41	1.43
4	250	127	72	0	0	0	0	0.35	0.62	0.79	1.15	1.5	1.53
5	250	164	100	0	0	0	0	0.4	0.79	0.96	1.36	1.73	1.74
6	290	175	146	27	0	0	0	0.47	0.81	1.0	1.73	1.76	1.77
7	290	183	90	18	0	0	0	0.5	0.94	1.1	1.75	1.78	1.78
8	290	183	127	36	0	0	0	0.56	1.0	1.2	1.77	1.78	1.79

TABLE NO. 14 Filter run with 5 mg/l Alum dose. Dose introduced in bed 3" from top. Flow rate 2 gpm/sq.ft.

Time from start of run in hrs	Turbidity in mg/l at depths							Head loss ft. at depths					
	3	6	9	18	33	36	eff	3	6	9	18	33	36
1	183	72	54	8	8	8	8	0.13	0.26	0.41	0.81	1.2	1.26
2	183	109	72	8	8	8	8	0.14	0.27	0.41	0.83	1.21	1.28
3	192	127	72	8	8	8	8	0.15	0.29	0.43	0.85	1.26	1.33
4	192	146	82	8	8	8	8	0.16	0.3	0.45	0.89	1.31	1.38
5	200	146	82	27	8	8	8	0.17	0.31	0.49	0.96	1.41	1.49
6	200	146	82	45	8	8	8	0.18	0.34	0.51	1.0	1.43	1.53
7	220	164	90	45	8	8	8	0.19	0.35	0.52	1.02	1.45	1.54
8	220	164	90	45	8	8	8	0.19	0.36	0.54	1.04	1.45	1.55

TABLE NO. 15 Filter run with Alum introduced at 6" from top. Alum dose 10 mg/l. Flow rate 2 gpm/sq.ft.

1	100	27	18	8	0	0	0	0.15	0.29	0.45	0.83	1.55	1.55
2	100	82	18	8	0	0	0	0.16	0.31	0.46	0.85	1.61	1.61
3	90	108	8	0	0	0	0	0.19	0.34	0.49	0.87	1.62	1.64
4	90	127	18	0	0	0	0	0.2	0.36	0.51	0.89	1.66	1.67
5	90	146	18	0	0	0	0	0.21	0.37	0.52	0.91	1.69	1.71
6	90	183	18	8	8	0	0	0.21	0.37	0.54	0.92	1.74	1.74
7	90	200	27	18	0	0	0	0.24	0.38	0.57	0.98	1.76	1.77
8	90	220	53	27	8	8	8	0.26	0.42	0.62	1.03	1.81	1.82

TABLE NO. 16 Filter run with Alum introduced at 9" from top
Alum dose 10 mg/l. Flow 2 gpm/sq.ft.

Time from start of run in hrs	Turbidity in mg/l at depths							Head loss ft. at depth					
	3	6	9	18	33	36	eff.	3	6	9	18	33	36
1	100	90	37	0	0	0	0	0.13	0.16	0.4	0.85	1.51	1.54
2	90	90	72	0	0	0	0	0.14	0.19	0.41	0.87	1.51	1.55
3	90	82	90	8	0	0	0	0.17	0.26	0.43	0.89	1.54	1.57
4	100	90	108	8	0	0	0	0.19	0.29	0.45	0.91	1.56	1.55
5	100	90	127	8	0	0	0	0.21	0.3	0.47	0.93	1.58	1.62
6	90	90	146	18	0	0	0	0.21	0.31	0.48	0.94	1.61	1.64
7	90	90	164	18	0	0	0	0.21	0.31	0.50	0.96	1.64	1.71
8	90	90	183	27	8	8	8	0.22	0.32	0.55	1.04	1.66	1.72

TABLE NO. 17 Filter run at 3 gpm/sq.ft. flow rate. Alum dose
10 mg/l. Dose introduced in bed 3" from top.

1	164	90	54	8	0	0	0	0.15	0.22	0.45	1.06	1.7	1.96
2	183	108	90	18	0	0	0	0.15	0.25	0.46	1.08	1.72	2.0
3	154	113	108	27	0	0	0	0.2	0.33	0.53	1.11	1.74	2.04
4	183	127	90	8	0	0	0	0.25	0.38	0.59	1.16	1.81	2.07
5	200	174	72	8	0	0	0	0.27	0.42	0.63	1.21	1.86	2.1
6	200	183	45	0	0	0	0	0.32	0.54	0.76	1.32	1.98	2.26
7	220	200	54	0	0	0	0	0.35	0.61	0.82	1.44	2.06	2.34
8	270	220	90	0	0	0	0	0.4	0.67	0.87	1.54	2.14	242

TABLE NO. 18 Filter run at 4 gpm/sq.ft. flow rate. Alum dose 10 mg/l. Dose introduced in bed 3" from top.

Time from start of run in hrs	Turbidity in mg/l at depths 3	6	9	18	33	36	eff.	Head loss ft. at depth 3	6	9	18	33	36
1	100	90	36	18	18	18	18	0.53	0.96	1.31	2.19	2.74	2.77
2	118	109	90	36	27	18	18	0.61	1.04	1.51	2.24	3.06	3.1
3	183	145	118	72	45	27	27	0.67	1.12	1.57	2.51	3.10	3.12
4	240	183	127	100	45	27	27	0.72	1.26	1.66	2.62	3.17	3.19
5	270	200	164	146	54	36	36	0.81	1.34	1.73	2.7	3.25	3.28
6	285	270	200	146	72	45	45	0.89	1.42	1.8	2.78	3.35	3.38

TABLE NO. 19 Filter run with 10 mg/l Alum dose. Dose added 3" above filter bed. Flow rate 2 gpm/sq.ft.

1	-	-	-	-	-	-	-	0.21	0.39	0.42	0.83	1.74	1.76
3	100	8	0	0	0	0	0	0.65	1.2	1.52	1.72	2.1	2.37
6	240	90	0	0	0	0	0	1.63	1.92	2.24	2.7	3.07	3.11
8	250	200	45	27	0	0	0	1.7	2.16	2.51	3.3	3.5	3.55
10	275	108	8	0	0	0	0	1.79	2.82	3.23	3.73	4.06	4.1
11	-	-	-	-	-	-	-	2.09	3.1	3.37	4.02	4.35	4.38
12	290	127	8	0	0	0	0	2.45	3.44	3.9	4.38	4.7	4.72
16	375	145	53	8	0	0	0	3.0	3.84	4.42	5.05	5.45	5.5
18	-	-	-	-	-	-	-	3.53	4.4	4.98	5.64	6.0	6.06
19	-	-	-	-	-	-	-	3.76	4.78	5.36	6.03	6.42	6.46
20	415	183	90	8	8	8	0	4.04	5.2	5.81	6.46	6.84	6.88

TABLE NO. 20 Filter run with 10 mg/1 Alum dose. Dose introduced in bed 3" from top. Flow rate 2gpm/sq.ft.

Time from start of run in hrs	Turbidity in mg/1 at depths							Head loss ft. at depth					
	3	6	9	18	33	36	eff.	3	6	9	18	33	36
2	200	72	8	0	0	0	0	0.26	0.48	0.65	1.0	1.32	1.33
5	220	164	58	0	0	0	0	0.4	0.8	0.95	1.37	1.75	1.75
8	290	164	72	0	0	0	0	0.56	1.0	1.25	1.75	1.79	1.8
10	335	182	90	8	0	0	0	0.77	1.29	1.64	1.95	2.15	2.16
14	350	200	108	18	0	0	0	0.96	1.54	2.21	2.49	2.66	2.67
16	-	-	-	-	-	-	-	1.03	1.98	2.72	3.04	3.23	3.26
18	415	275	127	27	0	0	0	1.42	2.26	3.01	3.31	3.51	3.53
20	-	-	-	-	-	-	-	1.74	2.44	3.32	3.61	3.8	3.82
22	450	310	164	36	0	0	0	2.46	3.26	4.07	4.4	4.6	4.62
24	-	-	-	-	-	-	-	2.5	3.51	4.08	4.44	4.66	4.68
26	-	335	200	90	0	0	0	3.12	4.09	4.7	4.7	4.89	4.92
29	-	335	200	127	8	8	8	3.46	4.35	4.72	5.05	5.26	5.28
31	-	-	-	-	-	-	-	3.92	4.8	5.24	5.56	5.76	5.8
32	-	350	200	146	18	18	18	4.8	5.98	6.45	6.74	6.87	6.94